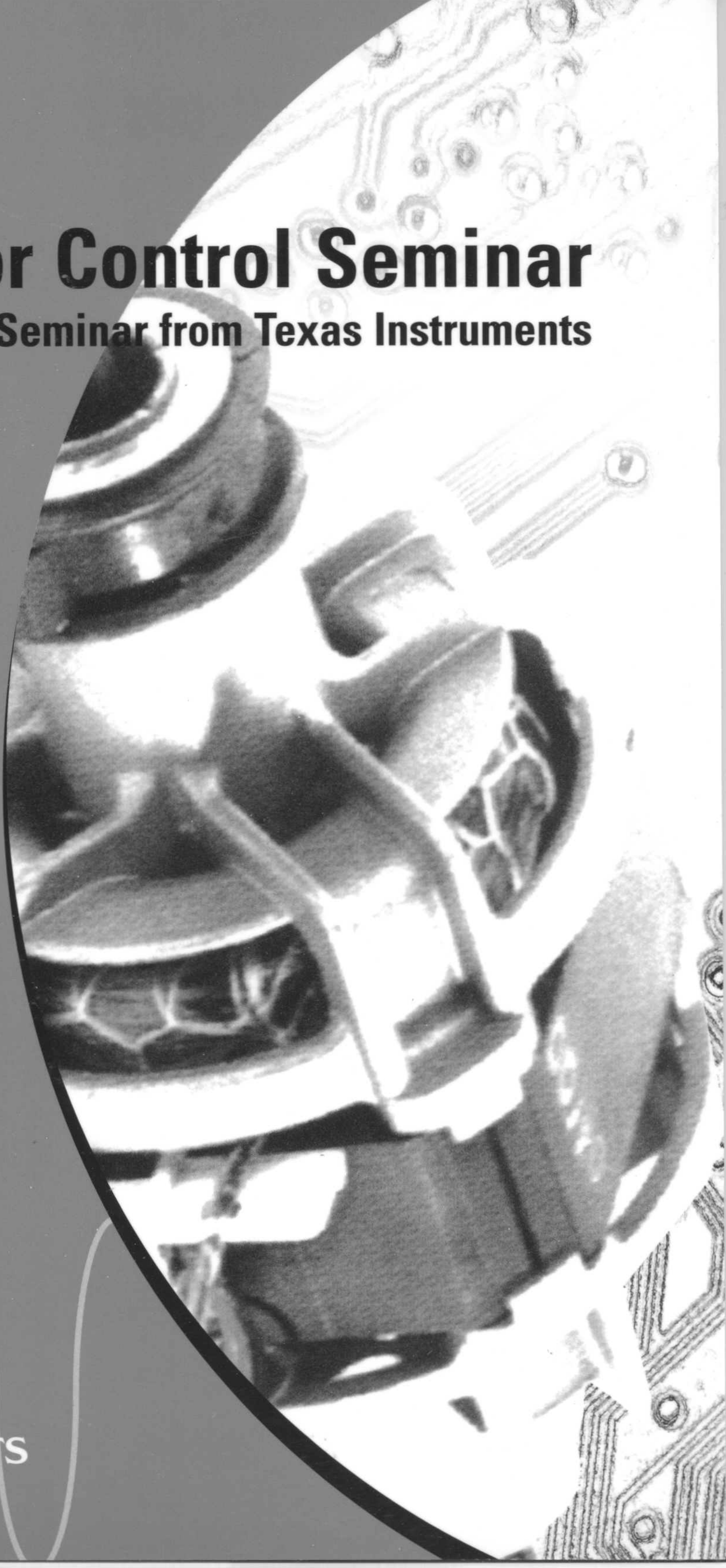
Digital Motor Control Seminar

A User's Application Seminar from Texas Instruments



Texas Instruments

Digital Motor Control Seminar

Texas Instruments

Digital Motor Control

Texas Instruments is pleased to present the Digital Motor Control Seminar to our customers. This is a detailed technical seminar on digital control of variable speed motors. TI's technical experts will demonstrate and explain the latest motor control techniques and the products available to designers to cost-effectively build motor control systems.

The first half will cover the TMS320C2000TM Digital Signal Controller family of devices targeted at the motor control market. We will emphasize the just released TMS320F280x series of controllers and demonstrate with real-world examples how designers can take advantage of their performance and integration in motor control systems.

The second half will cover analog solutions that complement the C2000 controllers and offer standalone options for the highest resolution and performance analog systems. The seminar will examine digital motor control applications from both the DSP and High Performance Analog perspective:

This material will include recommended methods of interfacing high resolution data converters, such as the ADS7869 and ADS1203, to the C2000 controllers and tackle system design issues to help designers rapidly move through their development cycle.

This seminar was written by the applications staff of Texas Instruments. The authors are Mohammed Arefeen, Kedar Godbole, Tom Hendrick and Miro Oljaca, Additional production support was provided by Cindy Williams.

Charles Wray

Member Technical Staff

Texas Instruments

Digital Motor Control

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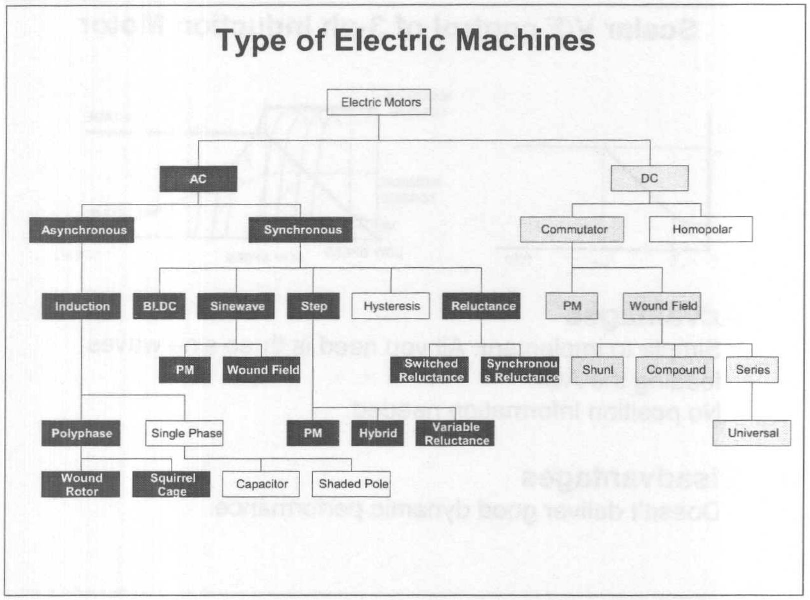
  - Q&A

This presentation reviews advanced motor control techniques and presents new devices for motor and motion control available from Texas Instruments.

It also presents an overview of the development tools available for developing motor control algorithms with TMS320C2000 DSPs. Finally, starter code available from TI for motor control with the C2000 DSPs is presented.

The goal today is to familiarize the audience with some of the advanced motor control techniques, and review some of the collateral available to get designs done rapidly with C2000 DSP Technology.

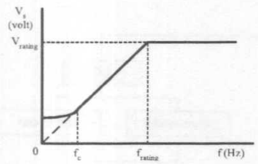


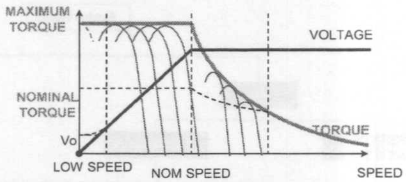
Let us begin by reviewing briefly the various types of motors.

Electric motors may be classified into AC and DC motors depending on the source of the excitation applied to the motor. Advanced motor control techniques primarily focus on AC machines, and within that the poly phase AC induction and permanent magnet machines are of primary interest. It is when controlling these types of machines, highlighted in the slide, that some of the most interesting performance gains are obtained.

Let us examine next some examples of how a more sophisticated control technique can achieve better performance from a motor.

Scalar V/F control of 3-ph Induction Motor





Advantages

+ Simple to implement: All you need is three sine waves feeding the ACI
+ No position information needed.

Disadvantages

– Doesn't deliver good dynamic performance.

The simplest control strategy for an AC machine is the (very familiar) constant Volts-Hertz control technique.

Since the speed of an AC induction motor is proportional to the speed of the rotating magnetic flux set up by the excitation, the simplest means of changing the speed of an AC induction motor is to change the frequency of the applied excitation. Changing the frequency of the applied excitation will change the frequency of the machine, but we must also manage another variable, and that is the magnitude of the excitation.

As the excitation frequency drops the rate at which the rotor MMF sweeps the stator windings is reduced. This means that the back-emf induced in the motor windings is reduced, and unless the magnitude of the applied excitation is reduced, the magnitudes of the currents fed into the motor will increase rapidly, causing saturation and overheating effects.

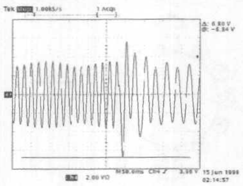
This scheme is extremely simple to implement, all that is needed is a means of generating a variable frequency / variable magnitude three phase sine supply.

For the most part this profile follows a constant slope with two exceptions: At high and low speeds, the profiles have a maximum and minimum voltage applied. At lower speeds, there is a minimum voltage needed for the motor to run properly, and at the high end, the applied voltage is limited by the insulation voltage rating.

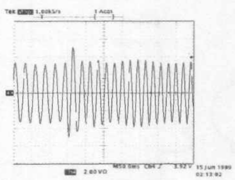
The downside of such a control scheme is that it does not deliver good dynamic performance, and also experiences a couple of trouble some side effects when used as the core of a closed loop variable speed drive.

Limitations of the Scalar Technique

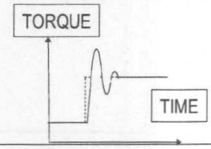
ACCELERATION



DECELERATION



Torque oscillation generates uncontrolled current overshoot:



- **High peak current:**
  - In V/f the rotor flux and current are not controlled: Current reaches values based on circuit parameters.
- **Poor response time:**
  - A solution to minimize these current overshoots is to decrease the performances of the speed regulator.
  - Slow speed regulator ⇒ poor mechanical behavior.

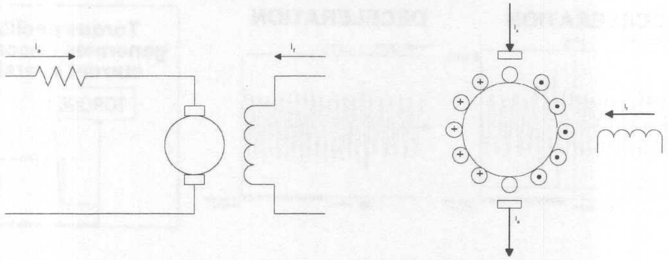
When the AC induction machine is used in a closed loop variable frequency drive, typically a PI or PID loop is closed around the base V/F control scheme. When a regulator attempts to control the motor speed, current spikes are observed especially when there are rapid load changes.

Secondly, when controlling speed, as the regulator is tuned to be progressively more aggressive, beyond a certain point, torque oscillations begin to appear. Now, the standard practice is to back off on the tuning of the regulator when this happens. This, however, means that a designer must trade of performance. The alternative is to accept the oscillations and the current spikes, meaning that a much larger (and more expensive) inverter must be designed to handle the current spikes. Besides, this can create issues, in that many specifications for safety will demand that the unit stay below a certain definite current limit.

Is there any other option? Yes, and to understand what is going on, it is useful to see what is happening under the hood.

In the above control scheme, there was no attempt to control the inter-relationship between the rotor flux and stator flux, which means that the they settle where ever an equilibrium is found. Disturbing this system there may be uncontrolled oscillations, since there is no active management of the system.

Torque Control of a Separately Excited DC Motor

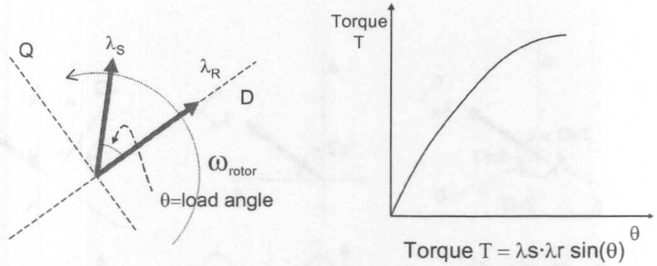


- Independently controlled armature current.
- Independently controlled or constant value of the field flux.
- Orthogonal spatial angle between the flux axis and the mmf axis to avoid interaction of the mmf and the flux.

Instantaneous torque control is possible if all the above three conditions are met at every instant of time.

A DC motor uses a mechanical commutator to manage the flux inter-relationship. When running a DC motor the commutator and rotor windings are so constructed, that the winding that generates the most torque is connected to the brushes. This is essentially a mechanical means of turning on the optimal winding, which ensures that the flux angle is as close to 90degrees as is possible, all the time.

Motor Flux Interaction in an AC Motor



Torque $T = \lambda s \cdot \lambda r \sin(\theta)$

λs and λr constant

- In an AC machine, the flux axis and the mmf axis is NOT naturally orthogonal.
- External control is necessary to maintain independent control of the flux components and also to ensure orthogonal relationship between the fluxes.

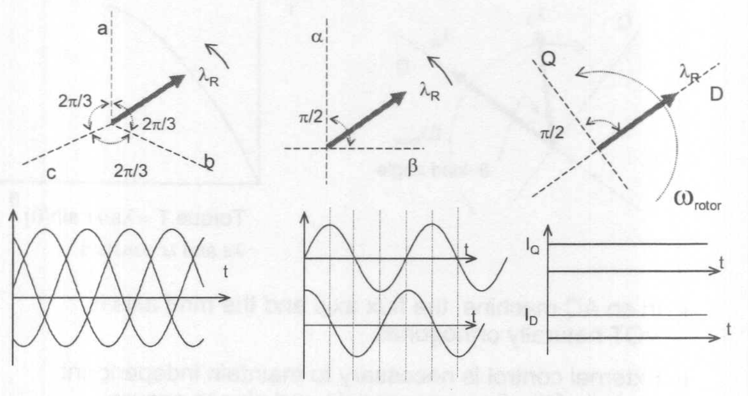
An examination of the inter-relationship of the fluxes is useful at this point.

The magnitude of the torque produced is proportional to the cross product of the rotor and stator flux. Thus for a given machine configuration, the torque produced is determined by the strengths of the two magnetic vectors, and the sine of the angle between them.

When there was no control of this inter-relationship, what happened when the high gain regulator tried to increase the speed rapidly? The torque increased to a point, but beyond a 90 degree point, the torque (as well as the back emf) actually dropped, before catching up again, as the back EMF dropped and let more current in.

One way to solve this problem is to move to a vector controller, in which the angle between the rotor and stator flux is maintained at an optimal value, at 90 degrees. To maintain alignment, it is necessary to have information on where the rotor flux vector position is. Current control is also needed to take control of the stator current vector.

Stationary and Rotating Reference Frames



Three phase reference frame

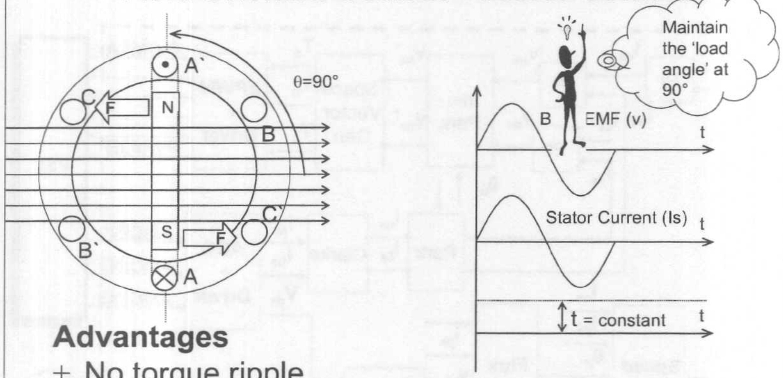
Two phase orthogonal Stationary reference frame

Rotating Orthogonal Reference Frame

Let us look at a few different reference frames. The three phase reference frame represents the rotating vectors as three sines: This means that the three components are not linearly independent and they interact. This makes analysis more complex.

Now if we transform to a orthogonal 2 axis reference frame, this makes the components independent. There is still, however one issue: the components are still sine waves, and it is more complex to create regulators to regulate sinusoidal quantities. This issue is solved by going to the synchronous reference frame, shown in the third frame.

Field Oriented Control - Vector Control



Advantages
+ No torque ripple
+ Better dynamic response

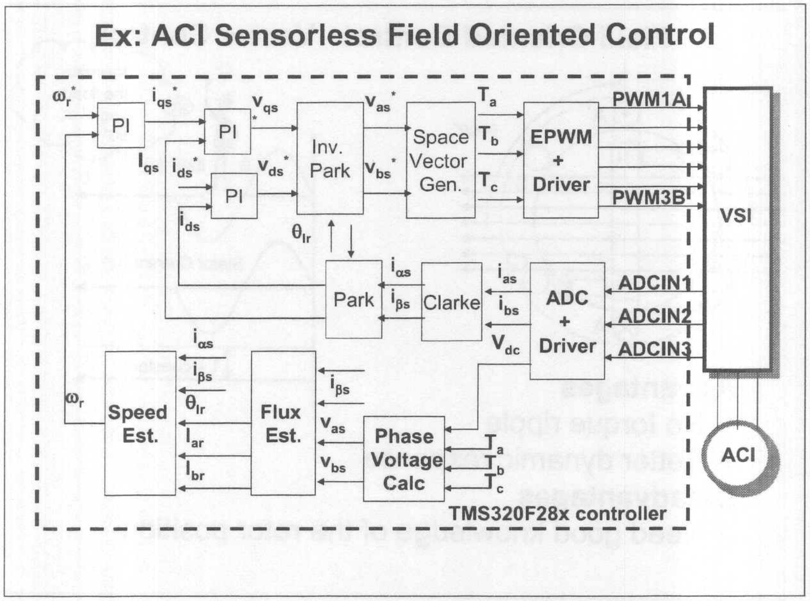
Disadvantages
– Need good knowledge of the rotor position

The field oriented control scheme for a PMSM is shown in the slide above. The control scheme for the ACI motor is along similar lines, but usually involves an additional flux angle computation step.

Since the field oriented control scheme strives to maintain the angle between the rotor flux and the stator flux as close to 90 degrees as possible, the performance is greatly improved, since the controller now controls the torque production actively.

The torque ripple is much smaller and since the currents are controlled, the issues associated with the current spikes are removed. One noteworthy point is the placement of the current controllers. The current controllers are usually placed in the synchronous reference frame, since this isolates them from the sinusoidal nature of the currents. Designing proportional-integral (PI) controllers to control dc current values is simpler than designing controllers to track sinusoids with accuracy.

FOC is a control strategy for 3-ph AC motors, where torque and flux are independently controlled. The approach is imitating the DC motors' operation. Direct FOC: rotor flux angle is directly computed from flux estimation or measurement. Indirect FOC: rotor flux angle is indirectly computed from available speed and slip computation.



Here is a block diagram of a sensorless motor drive system showing the motor control related functions.

From a mathematical perspective, the obvious place to start is with the known sinusoidal currents that can be measured in the stator. These currents can be represented as a single complex stator current vector.

The instantaneous currents in the stator phases can be represented as *ia, ib ic*, corresponding to the a, b, and c system axes. It can be transformed into a two-coordinate system that does not vary with time by using two transforms, the clarke transform and the park transform.

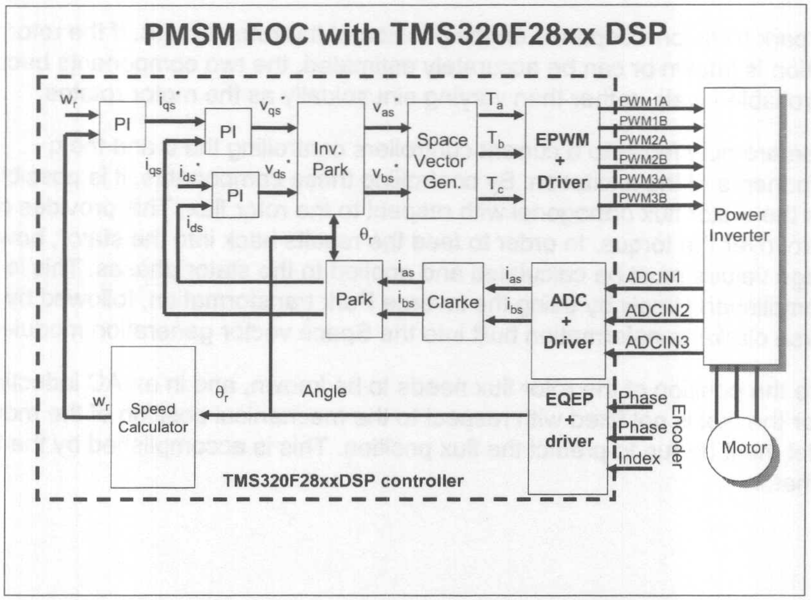
First the Clarke transform inputs the three-coordinate (a,b,c) vector and outputs a two-coordinate time variant vector (α, β).

To simplify the dynamical model, the stator current representation must still be transformed into a co-ordinate system that is synchronous with the rotor flux. This is accomplished by the Park transform. Here, the reference coordinates are *d* (flux) and *q* (torque) and the reference frame is with the *d* axis aligned with rotor the flux position, *θ*.

The park transform depends on the position of the rotor flux (θ). If the rotor flux position is known or can be accurately estimated, the two components become controllable levels, rather than varying sinusoidally as the motor rotates.

These are now fed in to a current controllers controlling the d and the q components of the excitation. By controlling these components, it is possible to align the stator flux orthogonal with respect to the rotor flux. This provides direct control over the torque. In order to feed the results back into the stator, however, voltage values must be calculated and applied to the stator phases. This is accomplished simply by using the inverse Park transformation, followed by the inverse clarke transformation built into the Space vector generation module.

Since the position of the rotor flux needs to be known, and in an AC induction motor the flux is not fixed with respect to the mechanical position of the motor, a model must be run to predict the flux position. This is accomplished by the flux estimator.



The field oriented control (FOC) of a permanent magnet synchronous machine is very similar to the AC Induction motor case, except that the process of obtaining the rotor flux angle is very straightforward. Since the rotor contains magnets mechanically mounted into the rotor, the rotor flux position is obtained by simply measuring the position of the rotor. Sensor less strategies are also possible, where the rotor flux is predicted, to avoid the mechanical sensor.

Comparative merits of FOC and Constant V/Hz

Performance Comparison Control Algorithms	Volts per Hertz Control	Vector Drive	Servo Drive
Velocity Loop bandwidth in Hz	1Hz	50 Hz	100 Hz
Minimum speed with full load (RPM)	90	0	0
Maximum speed with 25% load (RPM)	1.5 X Base Speed	2.5 X Base Speed	2.0 X Base Speed
Minimum acceleration time (seconds)	3	0.1	0.01
Minimum deceleration time (seconds)	3	0.1 w/DB	0.01
Maximum starting torque (%)	150%	200%	200%
Speed regulation at full load (%)	± 3% (base)	± 0.01% (set)	± 0.01% (set)

The numbers above are for comparison only. Specific system dynamics will affect exact data.

So what does vector control bring in terms of performance?

Generally speaking vector control increases the bandwidth of the motor systems. This means that the motor control system can respond faster to changes in the set points, and any disturbances to the controlled variable. In addition, the minimum speed at full load is now essentially zero. The starting torque is increased as well.

Another noteworthy point is that a vector drive has very little torque ripple.

All of these improvements mean that the vector drive can enable the system designer to choose a optimally sized motor for the task at hand, reducing costs. Since a vector drive controls currents, the inverter components, such as IGBTs, can be optimized as well.

Let us turn our attention next to how to implement such a vector control system and a few examples of how a advanced control algorithm impacts a system.

Digital Signal Controllers Outline

Part I: Advanced motor control

Need for a DSP

This presentation reviews advanced motor control techniques and presents new devices for motor and motion control available from Texas Instruments.

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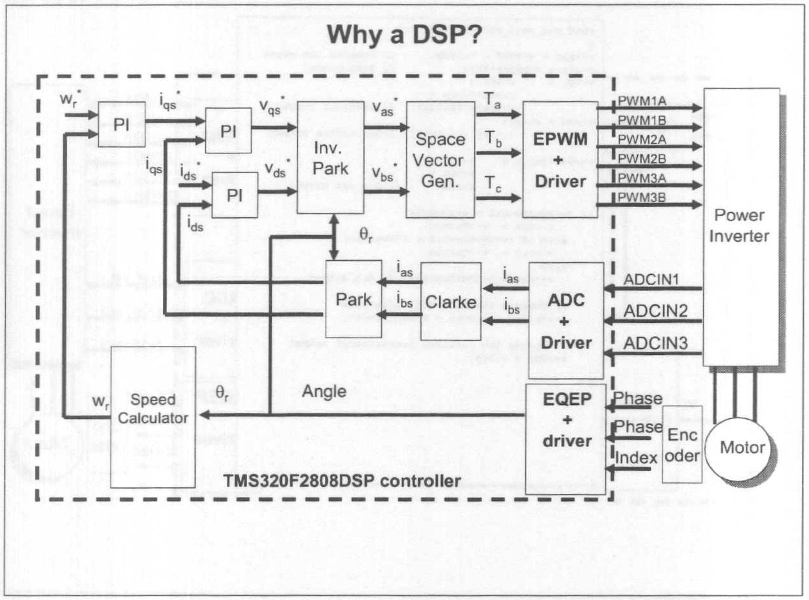
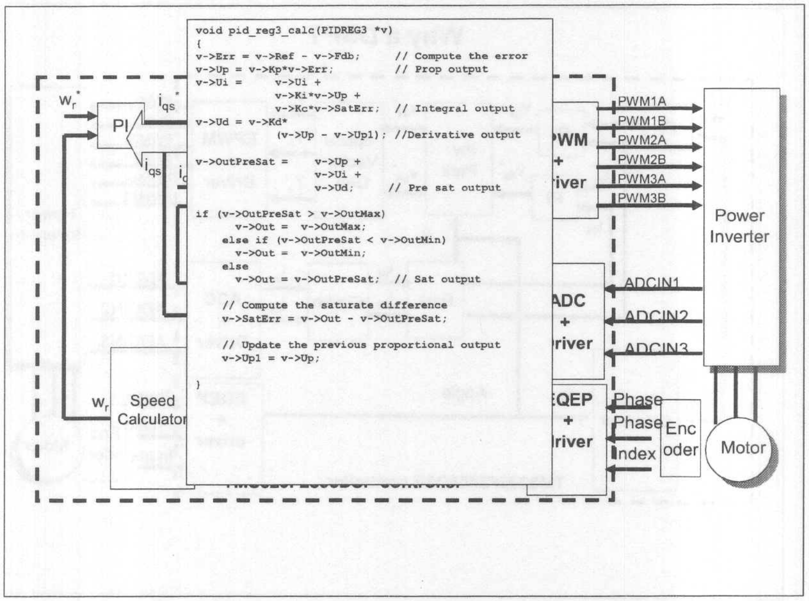
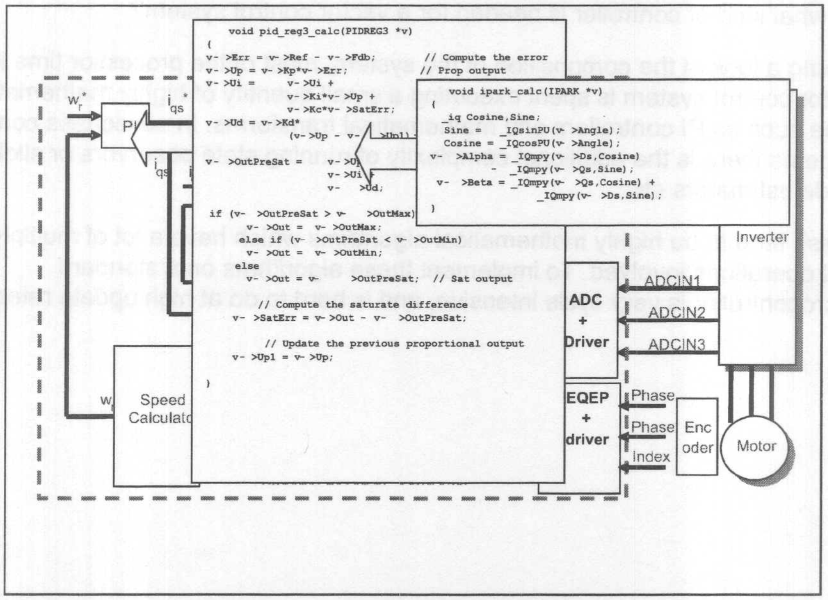


So what kind of controller is needed for a vector control system?

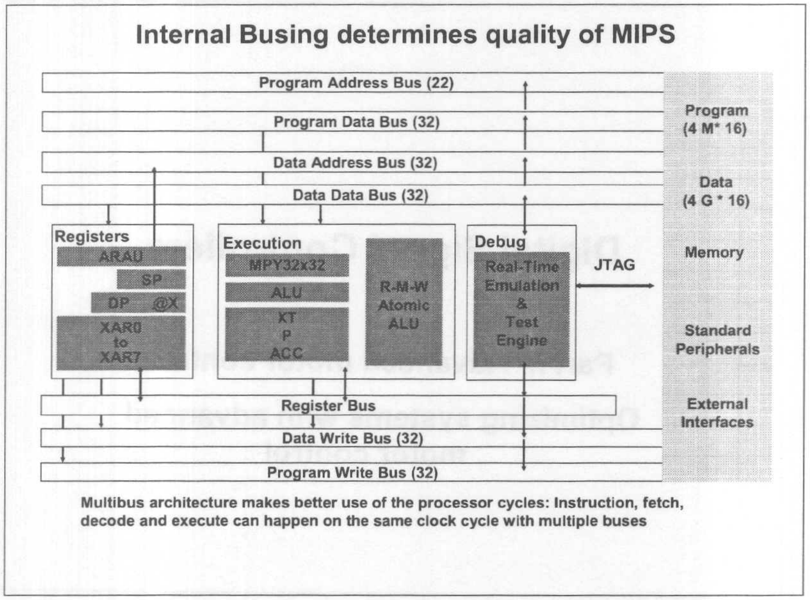
Taking a look at the composition of the system, most of the processor time in a motor control system is spent executing a small quantity of highly mathematical code such as PI controllers and mathematical transforms. In sensorless control systems there is the additional complexity of running state observers or sliding mode estimators etc.

These tend to be highly mathematical algorithms which have a lot of multiply and add operations involved. To implement these algorithms on a standard microcontroller is very cycle intensive, and is hard to do at high update rates.





This page shows the presentation build of codes.



The C28x was designed to address the need of an effective uniprocessor architecture that supports the needs described in previous slides before. There are 4 major block to the architecture: Program block, Register block, Execution block, and Test & Emulation block. To introduce the data flow we shall take examples from the instruction set.

An instruction is fetched from the memory and interpreted by the decoder (some processors call this the Instruction Register IR). This is the brain of the processor which generates all the control signals through out the processor.

Although this is a Harvard architecture, the C environment sees memory as a unified memory space with “functions and variables”. The Harvard architecture helps improve the performance. The large address space allows different physical spaces to map as a single unified logical space.

The CPU also supports single cycle dual operand instructions. This requires 2 operands read simultaneously. The processor make use of the program and data buses to archive the high throughput. This tightly coupled register block with execution block allows the C28x to be more flexible than the traditional DSP architecture. The multiple on chip buses allow the C28x to be superior than the traditional CISC and RISC architectures.

The C28x also supports various atomic instructions which enable this processor to run a multitask OS efficiently in an embedded environment.

In a complex embedded environment, real time debugging is becoming more important. The C28x is designed with hardware debugging capability built in. This debugger watches all internal bus activities and selectively reports the CPU status via the JTAG interface.

Digital Signal Controllers

Part I: Advanced motor control

Optimizing systems with advanced motor control

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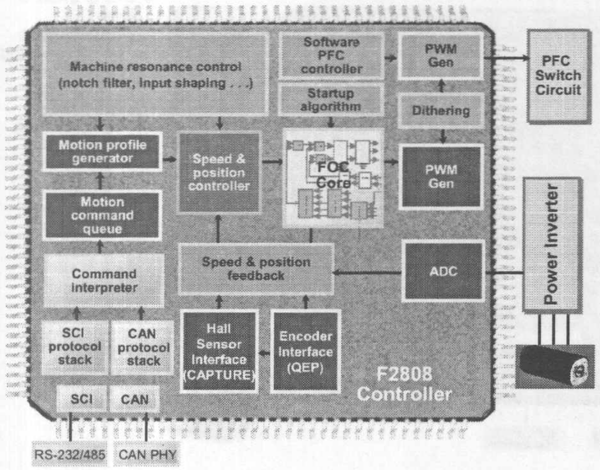
Servo Block Diagram



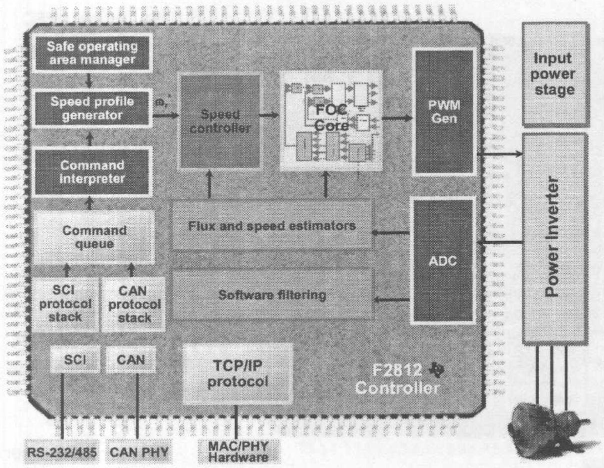
- Discrete PFC controller eliminated ($)
- Replaced trapezoidal or sine commutation with FOC: Enhanced performance
- Machine resonance control: Performance enhancement and cost saving on damper ($)
- Moved motion profile processing into same processor: Eliminates second microprocessor

This slide is an example of how advanced motor control changes a system. For example, the PFC function is now moved into the DSP controller, which implements it as a software algorithm. (Cost savings).

The six-step commutation in traditional servo amplifiers is replaced with a FOC commutation scheme. This means that the commutation is smoother, and removes torque ripple. Additional functions such as motion profile generation can be absorbed into the same controller, thus eliminating the need for a separate processor. This leads to further optimization in the system cost.

Functions such as machine resonance control may be implemented to simplify the mechanical system. Techniques to implement resonance control involve filtering strategies such as notch filtering applied to commands, as well as input shaping techniques which are applied to commands such as torque commands. These techniques generally focus on avoiding the excitation of vibration modes in the machine. The improved performance of the vector drive may allow simplification to the drive train leading to cost savings.

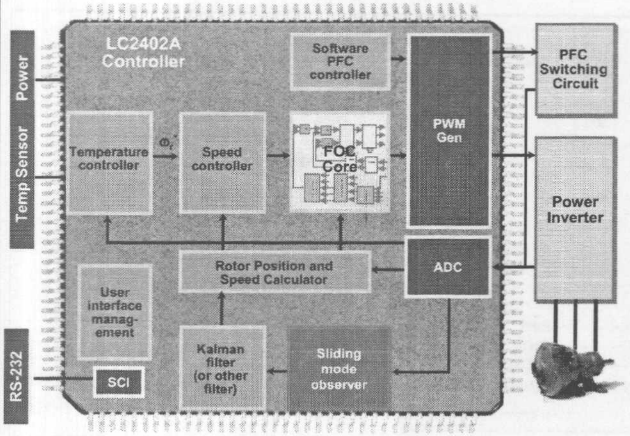
Industrial: AC Induction Motor Drive



- MIPS enable high performance
  - FOC gives full torque from zero to full speed
  - Enables four quadrant operation
- Software integrates a variety of "auxiliary" functions
- Flexible software enables one controller for many drives.

This is another example of how advanced control leads to system optimization.

Appliance: Refrigeration Compressor Control

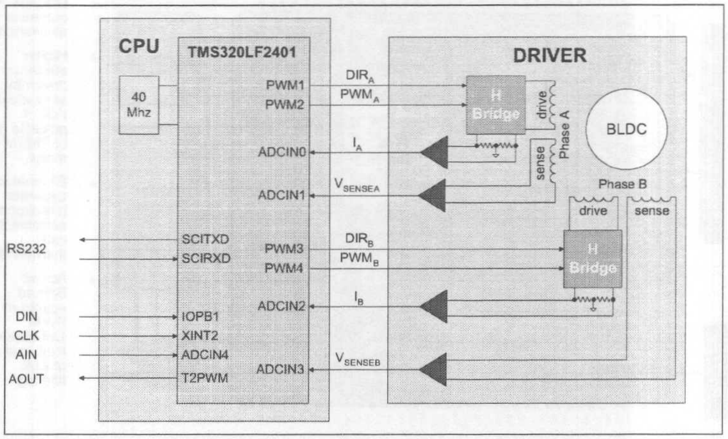


- Discrete PFC controller eliminated ($)
- Higher efficiency driven by sensorless FOC + possible use of PMSM motor.
- Eliminated separate (electronic/electromechanical) thermostat ($)
- Added Spread spectrum PWM Generation: Reduced size of EMI filtering

Parasiliti F., Petrella R., Tursini M.: "Rotor speed and position detection for PM synchronous motors based on sliding mode observer and Kalman filter", Proc. of the European Conference on Power Electronics and Applications (EPE), Lausanne, 1999.

This is another example of how advanced control leads to system optimization.

Sensorless Stepper Motor Control



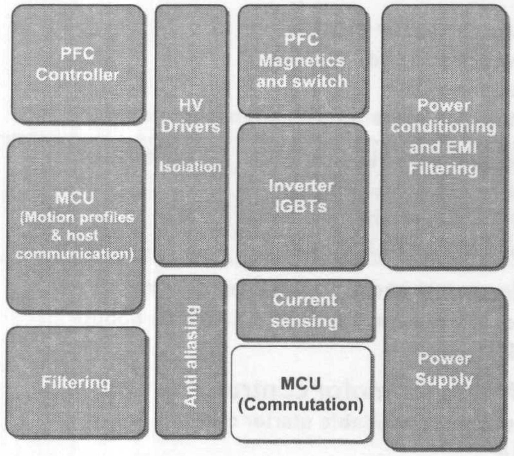
D3 Engineering (Rochester, NY)

Built into each six-wire stepper motor is an inherent drive and sense winding for each phase. A careful inspection of the internal motor wiring reveals that each phase winding consists of two half-windings, connected in series, with the common connection brought out as a single wire. Disconnect these two half-windings, bringing out the wires separately, and you have made an eight-wire hybrid stepper motor.

If you want to optimize the use of copper wire to produce motor torque, you can specify that the sense winding be wound with a smaller gage wire, since it does not carry any drive current.

The computation of the position in the DSP allows the elimination of the position sensor.

Servo Drive / Servo Amplifier Hardware Partitioning



Benefits from TI C2000™ Digital Signal Controller

Improved system performance

- Less torque ripple
- Higher control bandwidth
- Lower EMI profile

Lower system cost

- Lower component count
- Smaller system size
- Improved system reliability
- Easier to manufacture

Applications Summary:

What did we do here? We replace expensive physical elements with software, leading to a smaller cheaper board. Also replacing analog circuits with software means that trimming of analog circuits which must happen during manufacture is eliminated simplifying manufacturing. Another advantage is that software does not drift, so filtering and signal processing implemented in software is temperature independent, and free of component tolerances.

Digital Signal Controllers

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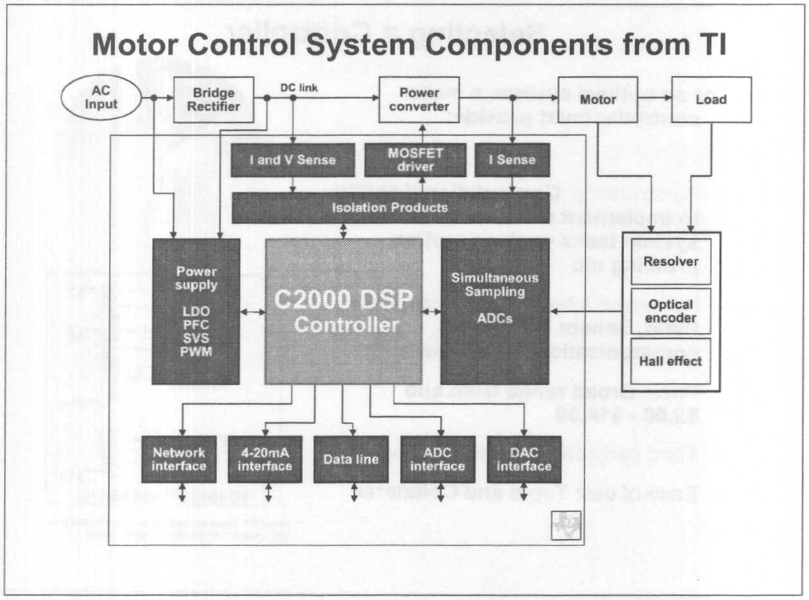


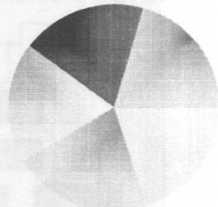
This slide depicts the wide variety of components available from Texas Instruments for the implementation of a Digital Motion Control system.

With the C2000 family of Digital Signal Processors (DSP), Texas Instruments can provide a complete "system on a chip" solution for low cost systems. Texas Instruments also has the capability to provide "one stop shopping" for external peripherals used in signal conditioning, high accuracy data acquisition, isolation products, current shunt and DC Link voltage monitoring, power supply and supervisory circuits as well as human interface products such as RS232 and CAN transceivers.

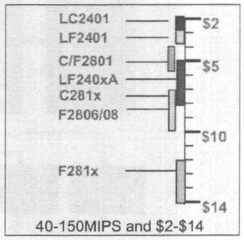
The heart of the system as shown above is the C2000 DSP Controller. The shaded boxes around the DSP represent all the associated components found within a typical DMC system. With such a diverse portfolio of products to choose from, Texas Instruments and Burr-Brown Products from Texas Instruments can provide solutions to the most demanding application.

Selecting a Controller

For an optimal system, a motor controller must provide:



- Performance: **Computational ability to implement motor control and system tasks such as motion profiling etc**
- Peripheral Integration: **Flash, ADC, PWM, Sensor interfacing, communications all on one chip**
- Price: **Broad range from sub $2.00 - $14.00**
- Third party development support
- Ease of use: **Tools and Collateral**



** 10ku SRP; Above numbers are for illustrative purposes only, contact TI for specific pricing information.

Digital Control Systems Require:

Performance

Up to 150 MIPS and 32-bit CPU for extended precision

Multi-bus architecture for simultaneous fetches

Pipelined Instructions for faster execution; Pre Fetch for fast execution from Flash

Single cycle MAC and Atomic operations for efficient math and control code computations

Fast interrupt response for low latency in control loops

Sensored or Sensorless

Mention more motor control specific details

Numerical Resolution – precise computations for control loops

Free IQMath Library allows floating point resolution on a fixed point machine without sacrificing cycle time

IQ Math Quote from Baldor

Ease of use

C language efficient core, free modular motor specific code, realtime O/S, best in class IDE, real-time debug and analysis, pre coded peripheral drivers, code security

Low System Cost

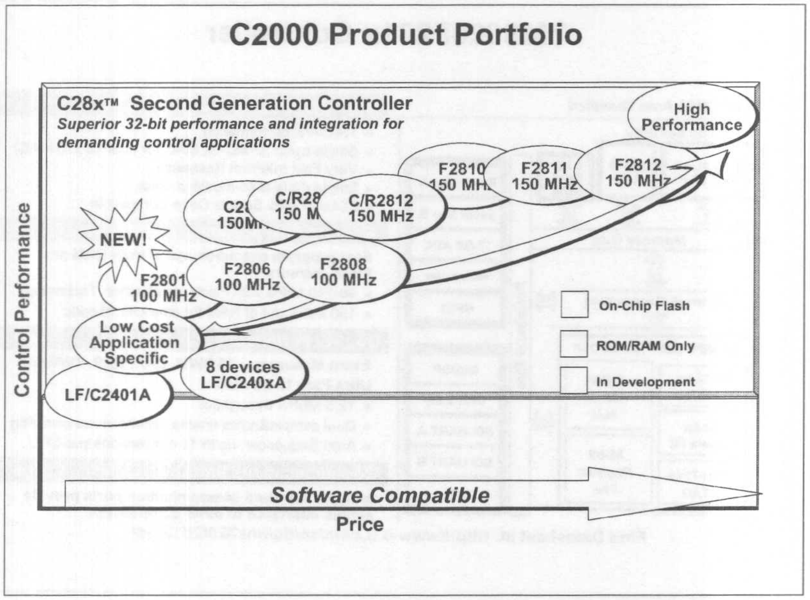
40 MIPS Controllers from sub $2 ROM and sub $3 Flash

150 MIPS Controllers from $7 ROM and $13 Flash

100 MIPS Controllers on roadmap for sub $5 Flash

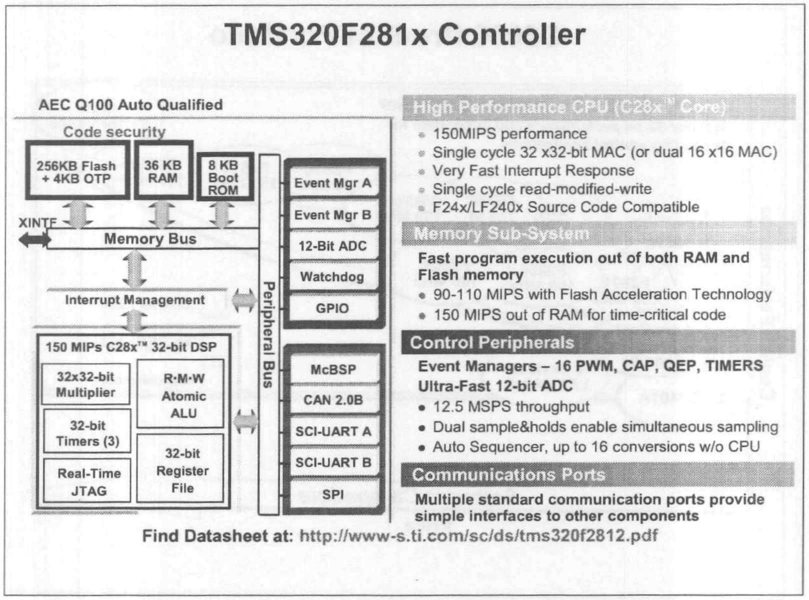
Reduced development costs from ease of use tools, ability to develop in floating point, and modular S/W

Reduced costs from integrated on-chip peripherals and reduced footprints



C2000 DSC Portfolio:

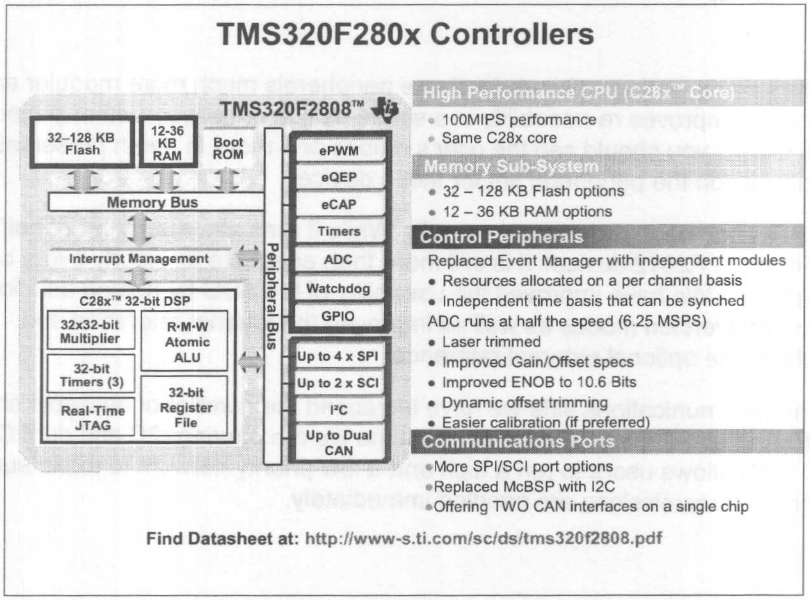
1. TI has a well-established second-generation DSC platform in production today. Competitors are still offering first generation architectures that lag behind in performance, integration, and ease of use.
2. TI has 18 C28xx devices with Flash (F), Custom ROM (C), and RAM-only (R) options.
3. The F280x devices are all pin compatible. The x2810 and x2811 devices are pin compatible.
4. All x281x devices are in production today. The F280x devices are also in production now.
5. THE 24x family has been available since 1997 and are still available today. TI PLANS TO CONTINUE PRODUCING THEM AS LONG AS THERE IS DEMAND. TI invented the market for digital signal controllers and is still the leader.
6. TI ensures that developers can reuse their software investment by keeping software compatibility as we introduce new devices.



The F2812 and F2810 are the most powerful embedded control DSPs in the industry. These devices are based on a 32-bit DSP core delivering 150 MIPS of performance on a flash process and an impressive 32 x 32bit MAC in a single 6.67ns cycle.

These DSPs also uniquely feature a large amount of fast-access on-chip flash memory so that code can be executed internally without adding costly external flash memories.

In addition, these devices incorporate a high-precision ultra-fast analog-to-digital converter (ADC) together with many control and communication peripherals for truly single-chip designs.



The TMS320F280x core is the same as C28x (F2812) except we redesigned for only 100 MHz performance to reduce die size and cost. These devices still obtain the 32-bit core architecture, 32x32-bit SINGLE cycle multiply accumulate (required for any sort of math – which is what drives improved control techniques), and fast interrupt response time. Most DSPs are poor at responding to interrupts. In a control system it is imperative that you are able to quickly stop processing and respond to real time system interrupts or your control system can fail.

Memory: these devices have a very large RAM for their price points and also include field reprogrammable flash memory with code security – a must in the embedded control market today. Our flash memory is the industries best in terms of being able to execute closer to full speed clock then our competitors.

Peripherals: We've totally redesigned what use to be called the Event Manager. The modules are now fully independent and include improved feature sets. Besides the improved features,

this has made writing software for these peripherals much more modular and drastically improves re-useability in a single design or between other projects. For more details you should see the user's guides or a more in depth presentation specifically on the peripheral set for these devices.

The ADC has been redesigned as well. While it runs at a maximum of half the speed of the F2812 devices it is still more then adequate for nearly every control application. We have improved the useability of the ADC by adding additional start of conversion modes as well as improved the internal reference and simplified the optional external reference.

On the communications side we have increased the number of available channels of SPI and UART ports and for the first time we are offering I2C and dual CAN. Dual CAN allows users to run a high and a low priority network to make sure that important transmissions are handled immediately.

Digital Signal Controllers

Part II: TI Silicon for motor control: What's new?

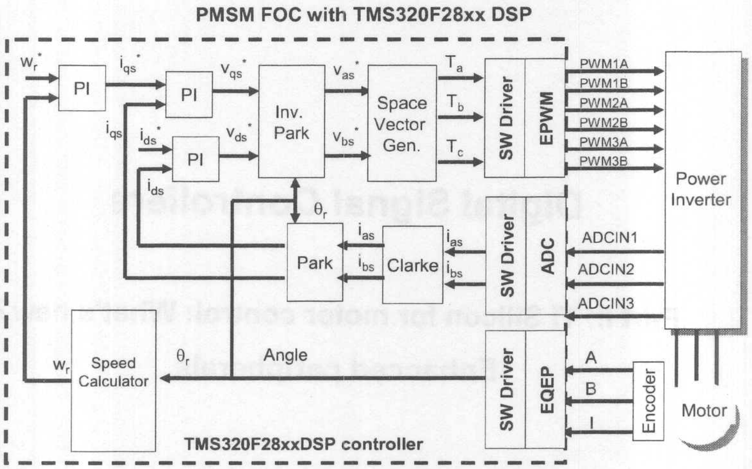
Enhanced peripherals

This presentation reviews advanced motor control techniques and presents new devices for motor and motion control available from Texas Instruments.

It also presents an overview of the development tools available for developing motor control algorithms with TMS320C2000 DSPs. Finally, starter code available from TI for motor control with the C2000 DSPs is presented.

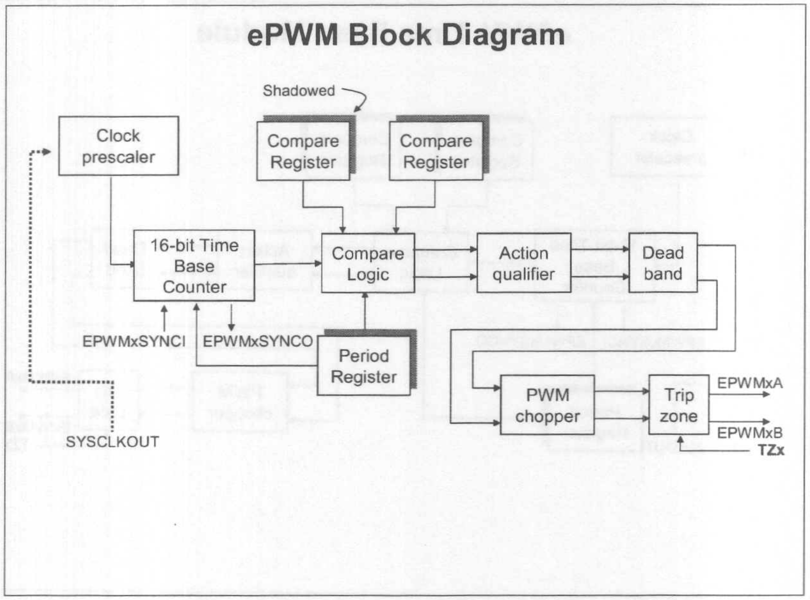
The goal today is to familiarize the audience with some of the advanced motor control techniques, and review some of the collateral available to get designs done rapidly.

An example system



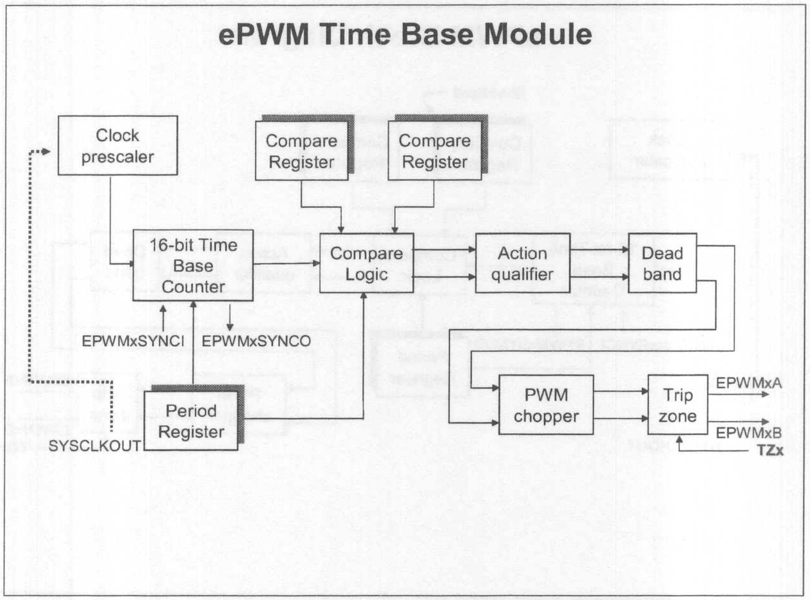
Let us look at the PMSM FOC system from a peripheral point of view. The EPWM units generate pulse width modulated waveforms for driving the inverter outputs. The ADC is used to measure analog quantities fed back from the system. The EQEP is used to keep track of the system.

The F280X DSP controllers offer enhanced peripherals, to interface with the motor control system. Let us explore these peripherals next.



This slide shows an overview of an EPWM module with some of the main components:

The time base module generates the time varying ramp (or up/dn) signal, which then the counter compare unit generates events from. The action qualifier takes various actions based on these, and then the post processing modules add dead band, polarity selection, PWM chopping functions.

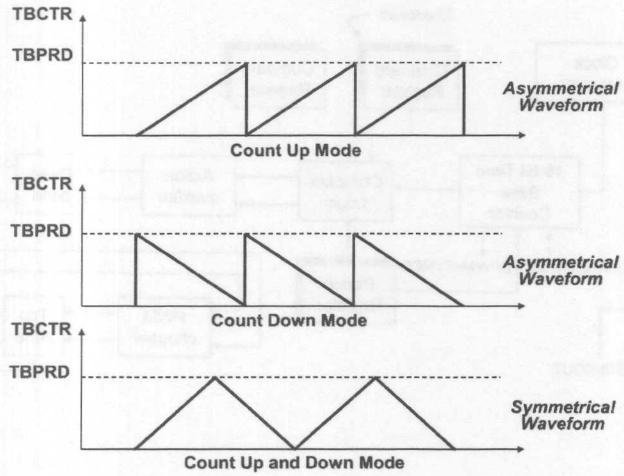


Let us now take a step by step look at some of the modules that make up one EPWM unit.

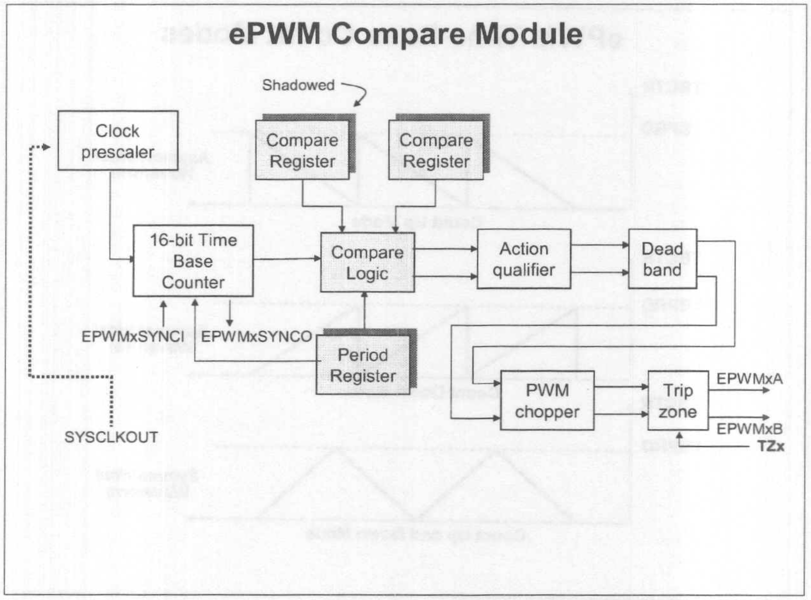
TB – sets the PWM period, frequency and phase relation to other modules

CC – controls the PWM duty cycle (on time / off time ratio)

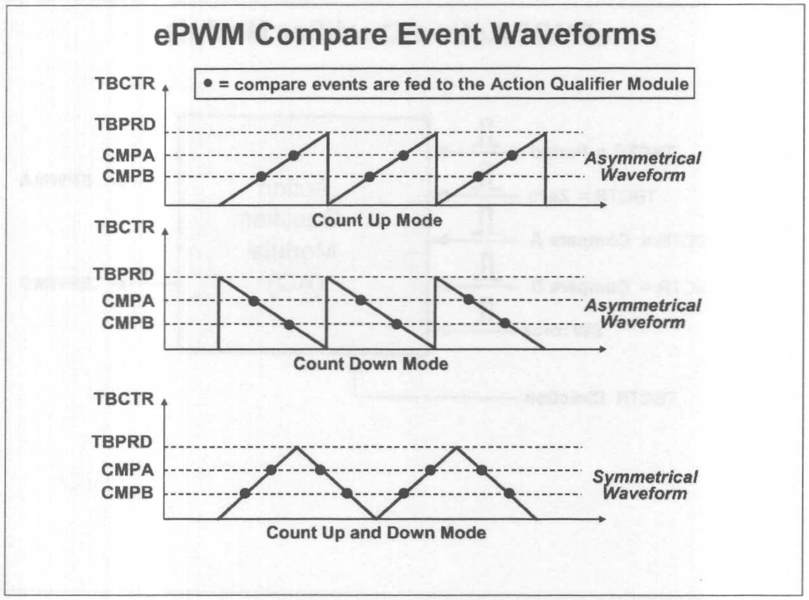
ePWM Time-Base Count Modes



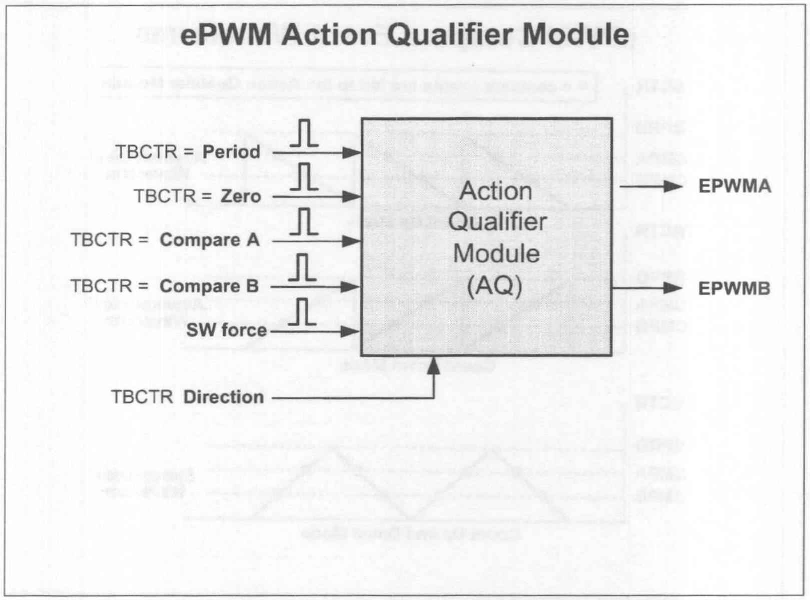
This slide shows the waveforms generated by the time base counters in the EPWM units. Straight up count, down count, as well as up-down count waveforms can be generated.



The compare module generates compare events, as can be seen on the next slide.



Compare events are generated when the contents of the compare register match the output of the time base generator.



The AQM is the “heart” of PWM waveform construction.

It is Event / Action driven, i.e. any Event can become an Action if programmed.

ePWM Action Qualifier Actions

for EPWMA and EPWMB

Events		Actions: Nothing	Actions: Clear Lo	Actions: Set Hi	Actions: Toggle
TBCTR (Up) equals:	Zero (ZRO)	Z ×	Z ↓	Z ↑	Z T
	CMPA (CAu)	CA ×	CA ↓	CA ↑	CA T
	CMPB (CBu)	CB ×	CB ↓	CB ↑	CB T
TBCTR (Down) equals:	Period (PRD)	P ×	P ↓	P ↑	P T
	CMPA (CAd)	CA ×	CA ↓	CA ↑	CA T
	CMPB (CBd)	CB ×	CB ↓	CB ↑	CB T
S/W force		SW ×	SW ↓	SW ↑	SW T

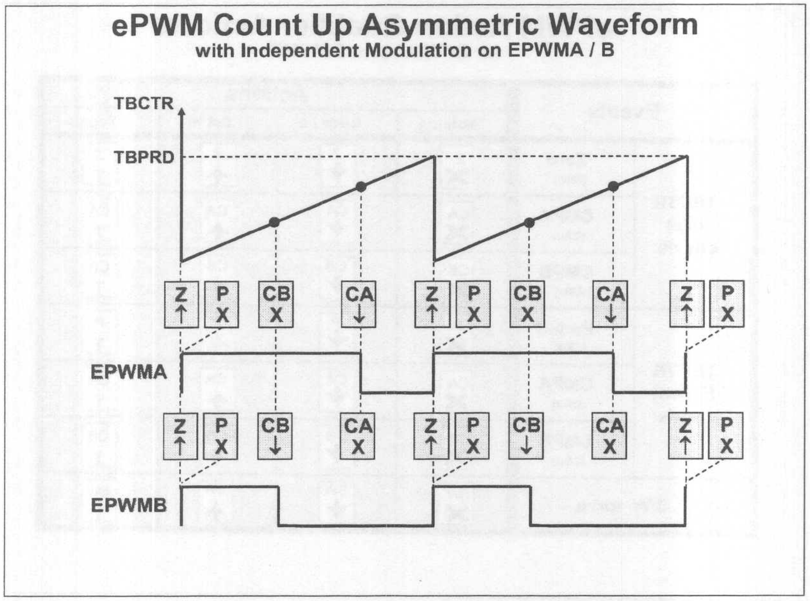
The possible events are shown above. There are 6 H/W events plus a user controlled S/W event.

The possible actions (shown in red) are:

- Do Nothing
- Clear PWM output to a low
- Set PWM output to a high
- Toggle the PWM output.

No guessing or confusion on waveform polarity (active Hi / Lo ?) Both the time instant a waveform changes, and it's polarity are clearly defined by the AQM.

The "Action markers" shown (as will be seen) are a convenient way to show the waveform construction process.



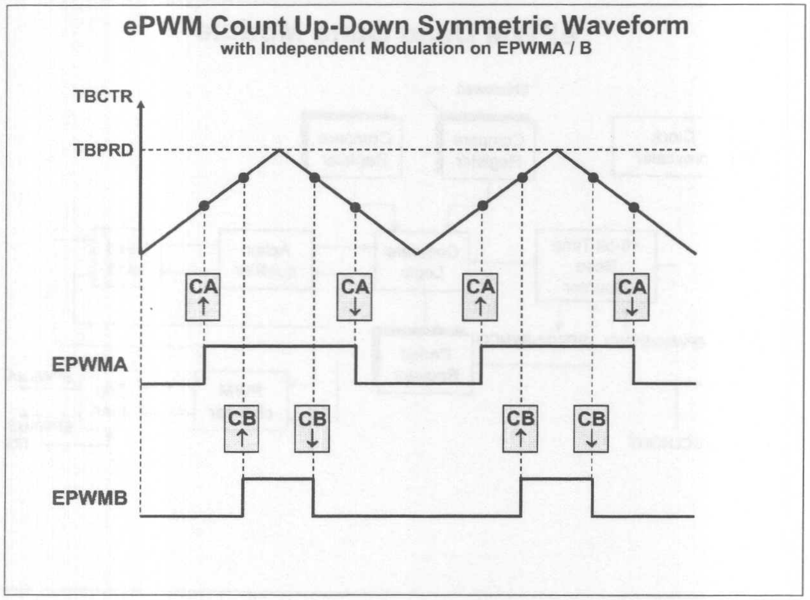
This is the simplest PWM example.

It is setup to control 2 PWM pins with independent duty cycle and same frequency. CMPA controls the duty of EPWMA and CMPB for EPWMB

For clarity, all markers are shown here, including the “Do Nothing” (X)

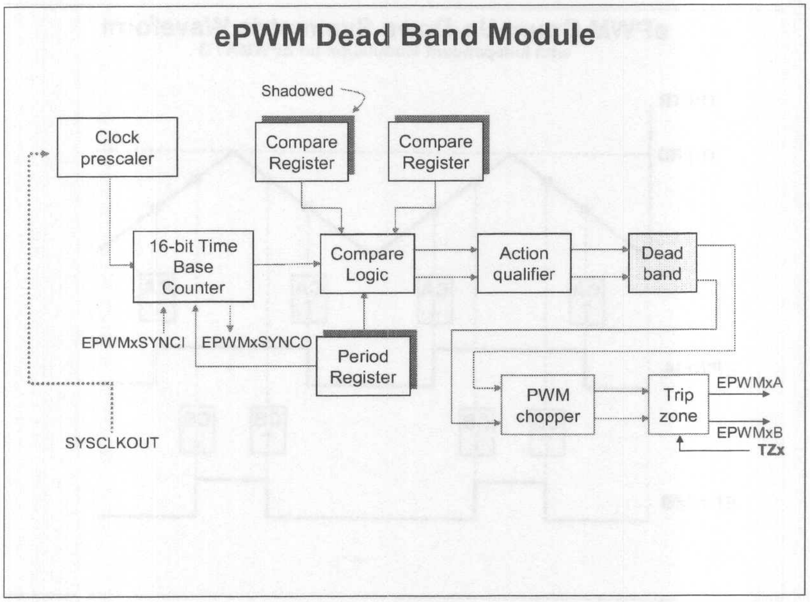
The events used are ZRO, CAu, CBu.

Run-time code needs to write only to CMPA and CMPB registers to change the duty cycle.



This shows the generation of a symmetric PWM. The compare A up count event is used to set the EPWMA pin, and the compare A down count match is used to clear the pin. This generates a symmetric PWM.

A similar set up for EPWMB shows the generation of a symmetric PWM of independent duty cycle on the EPWMxB pin.



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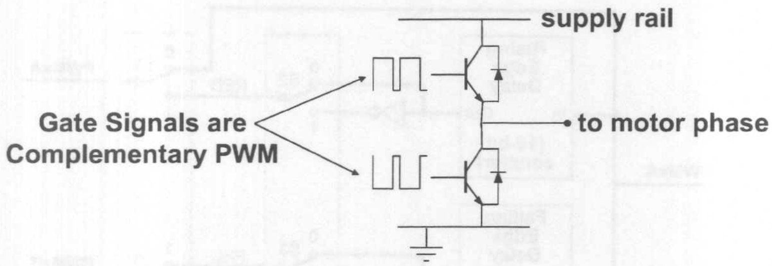
Motivation for Dead-Band



- Transistor gates turn on faster than they shut off
- Short circuit if both gates are on at same time!

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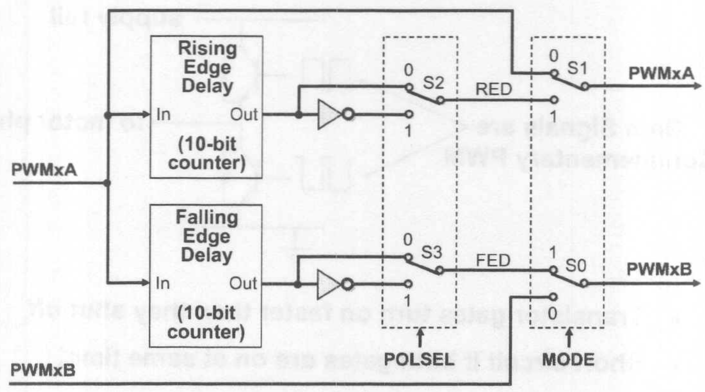
ePWM Dead-Band Module Block Diagram



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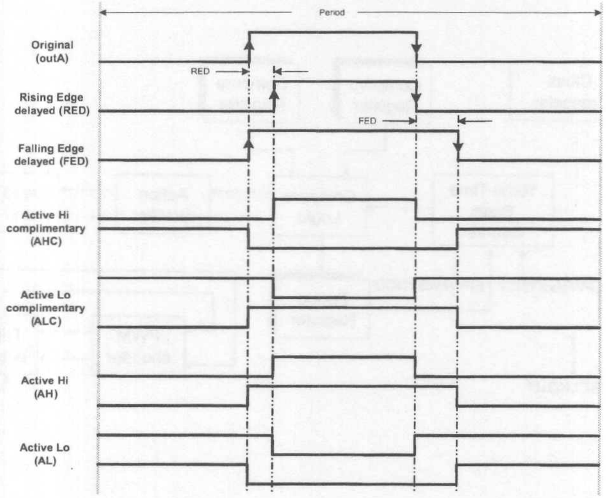
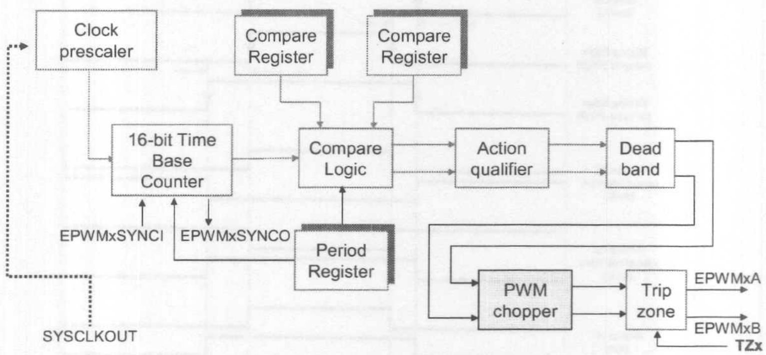
Dead band module waveform generation



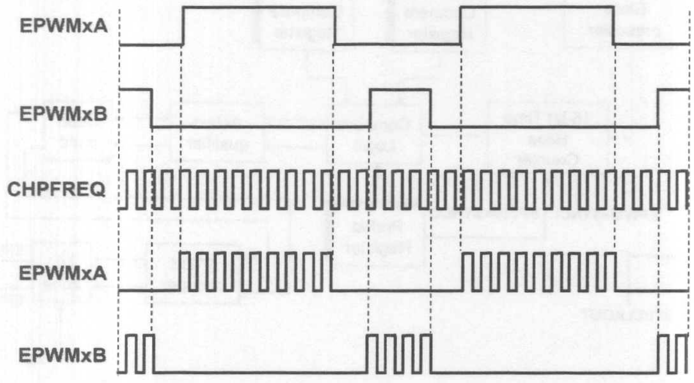
Waveforms show how all the common dead-band polarities are generated.

ePWM Chopper Module

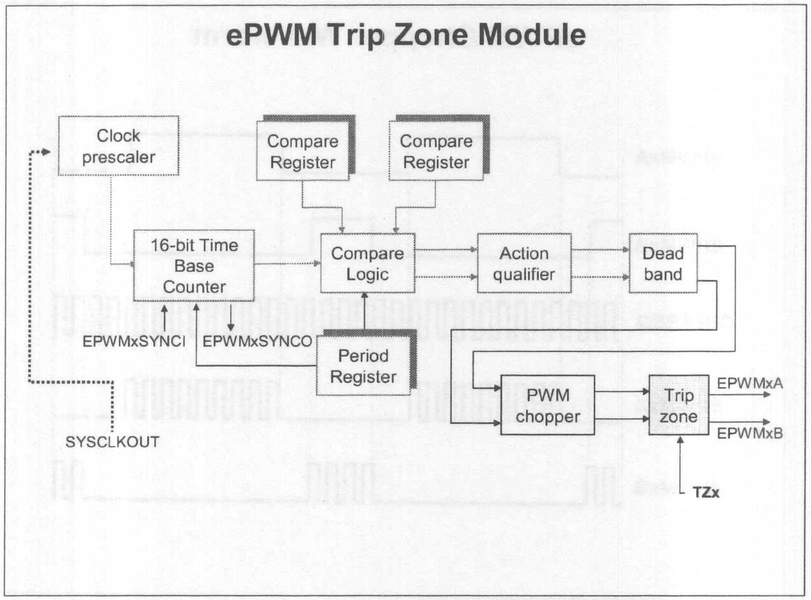


Let us take a closer look at the EPWM chopper module.

ePWM Chopper Waveform



The chopper module generates a chopped waveform as shown in the diagram. This allows the use of pulse transformers, to drive output stages, in designs which use thyristors for instance.

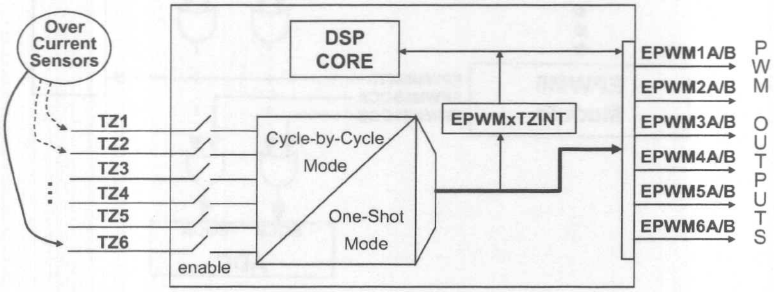


Next, we turn our attention to a module that serves a protective purpose, to protect the power devices in the inverter

Power Drive Protection

- Interrupt latency may not protect hardware when responding to over current conditions or short-circuits through ISR software
- Trip-Zone has a fast, clock independent logic path to high-impedance the EPWMxA/B output pins
- Supports: #1) one-shot trip for major short circuits or over current conditions

  #2) cycle-by-cycle trip for current limiting operation



The 2808 device has allocated 6 Trip Zone pins for purpose of fault triggering.

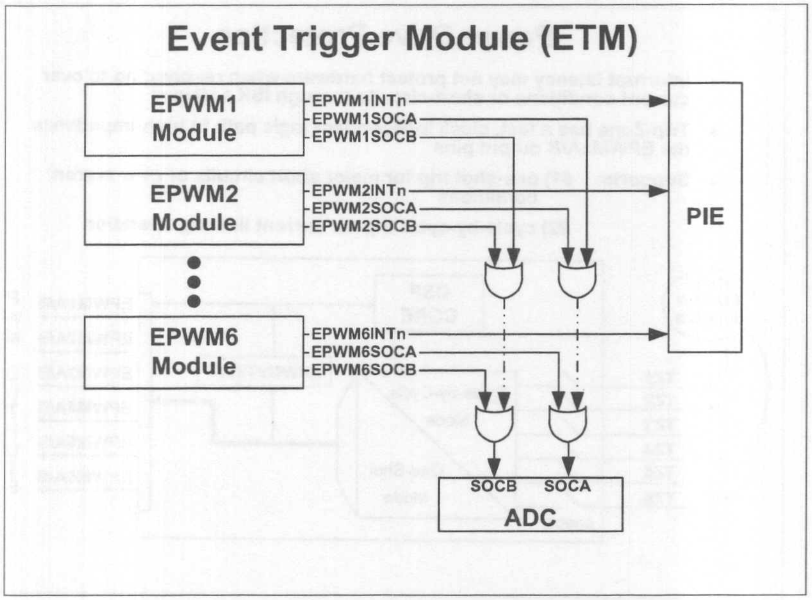
All pins (TZ1→TZ6) are identical and common to all EPWM modules.

Each module can choose which pin (i.e. zone) to use and what action is taken when a trigger on this pin occurs.

For example:

1. All EPWM module outputs (A & B) can be made to respond to a single TZ1 input trip signal, i.e. all on same zone.

2. Each EPWMx module (1→6) can respond to each TZx input (1→6) respectively. Or combinations there of.



All EPWM modules are linked to the PIE (Peripheral Interrupt Expansion) and ADC through 3 trigger (or request) signals

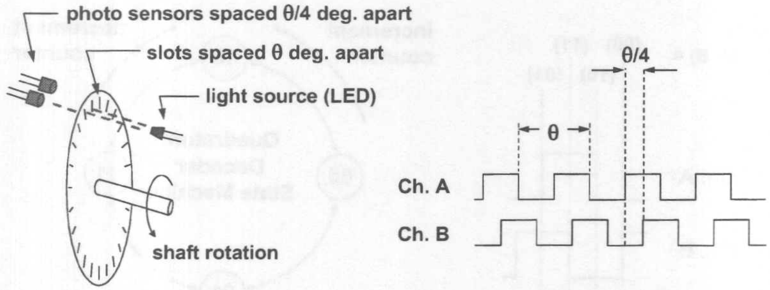
To allow for better CPU utilization and minimize Interrupt context save/restore, event triggers are pre-scaled.

Triggers can be made to fire every time, every 2nd and every 3rd time.

This allows PWM frequencies to run at higher rates than the CPU sampling / Interrupt rate without incurring unwanted ISR calls.

What is an Incremental Quadrature Encoder?

A digital (angular) position sensor



Incremental Optical Encoder

Quadrature Output from Photo Sensors

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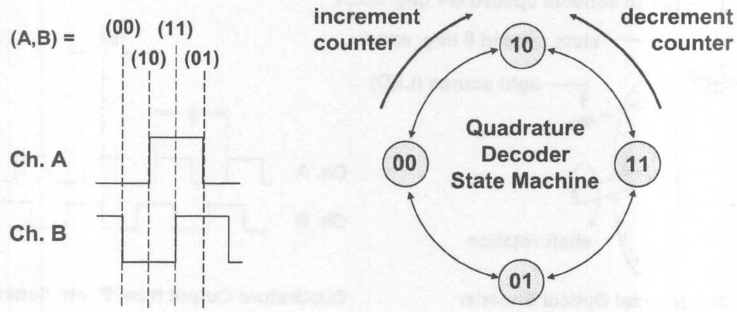
How is Position Determined from Quadrature Signals?

Position resolution is θ/4 degrees



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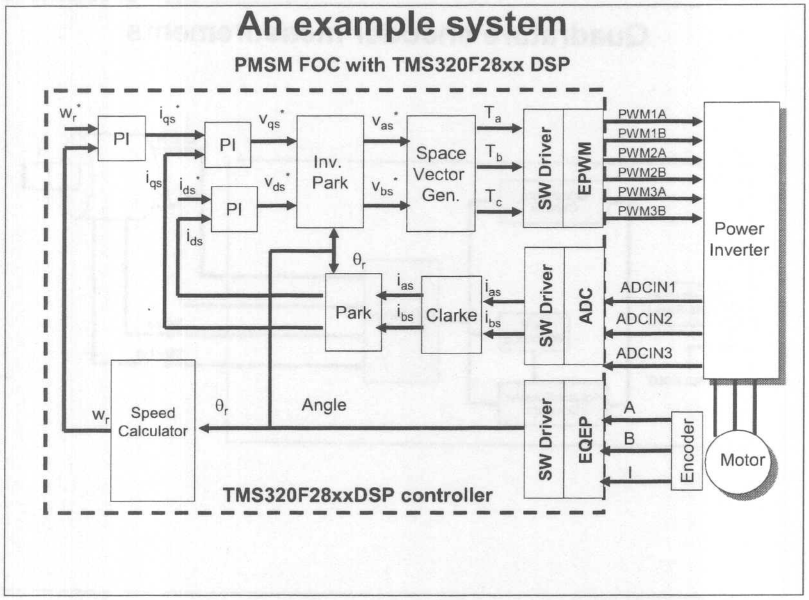
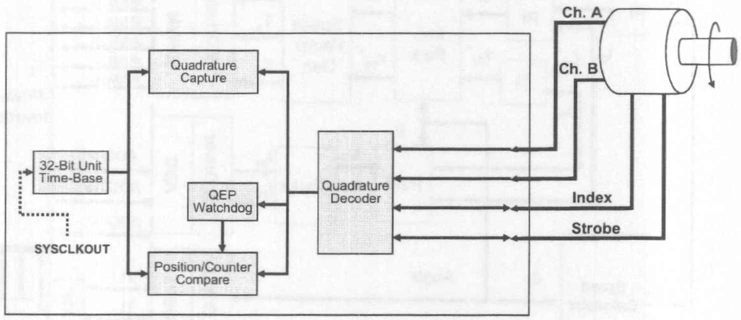


Let us look at the PMSM FOC system from a peripheral point of view. The EPWM units generate pulse width modulated waveforms for driving the inverter outputs. The ADC is used to measure analog quantities fed back from the system. The EQEP is used to keep track of the system.

The F2808 DSP controllers offer enhanced peripherals, to interface with the motor control system. Let us explore these peripherals next.

Quadrature encoder measurements



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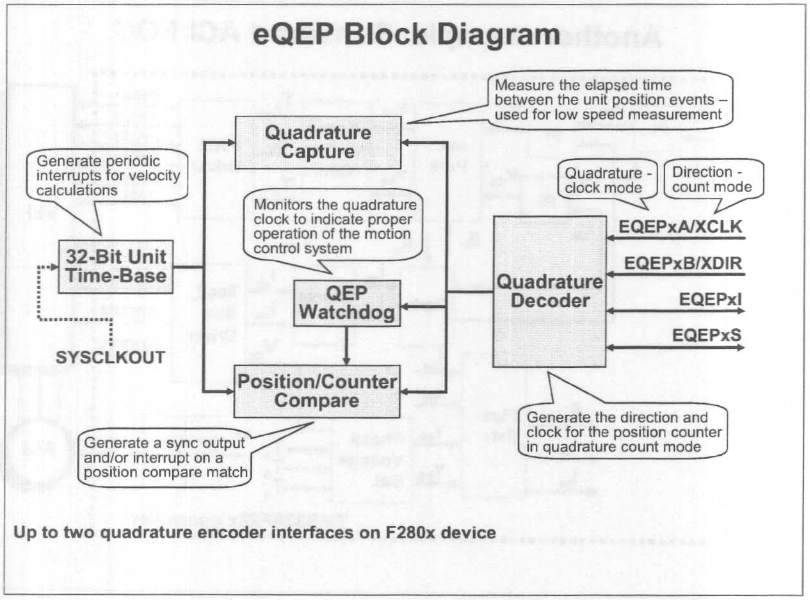

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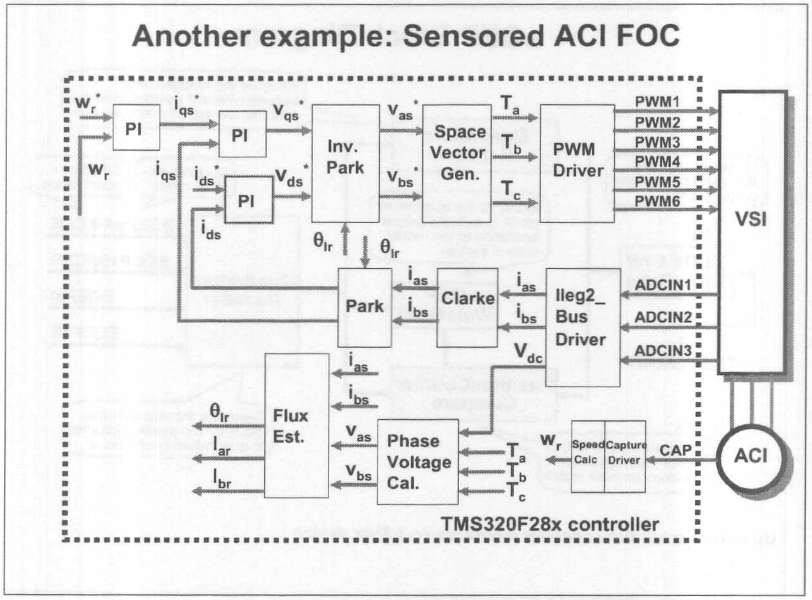
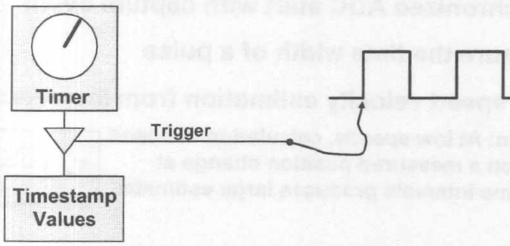


This is a slide from the discussion of the FOC of an AC induction motor, which we looked at previously. This uses the capture sensor to close a speed loop in the sensored version of the control. The capture sensor is used to time pulses, and we look at it next.

Capture Units



- Capture module timestamps transitions on capture input pin
- Four capture registers (per capture module) - associated with a capture input pin
- Up to four capture modules per device

The capture units are used to 'time stamp' events, which allows the control software to determine the speed at which external events are occurring.

Some Uses for the Capture Units

- **Synchronized ADC start with capture event**
- **Measure the time width of a pulse**
- **Low speed velocity estimation from incr. encoder:**

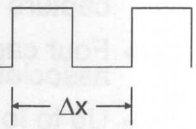
Problem: At low speeds, calculation of speed based on a measured position change at fixed time intervals produces large estimate errors

$$v_k \approx \frac{x_k - x_{k-1}}{\Delta t}$$

Alternative: Estimate the speed using a measured time interval at fixed position intervals

$$v_k \approx \frac{\Delta x}{t_k - t_{k-1}}$$

Signal from one quadrature encoder channel

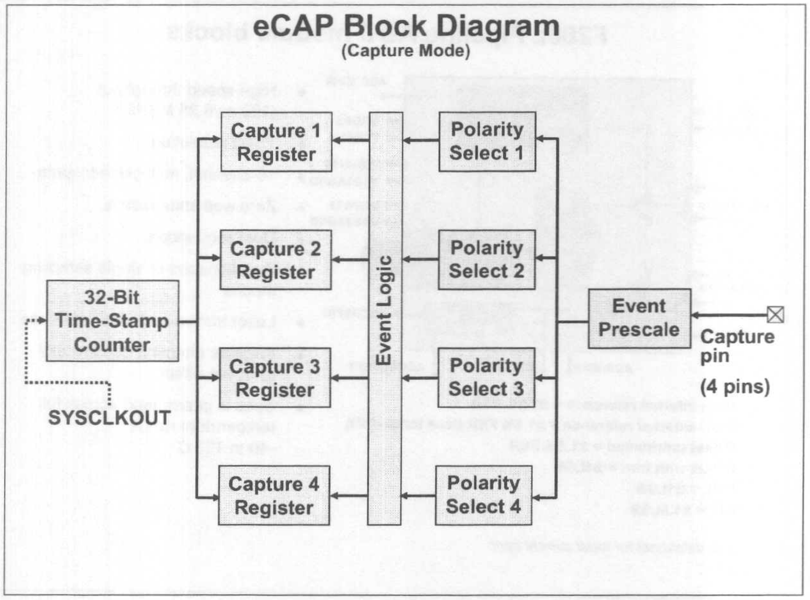


LOW SPEED VELOCITY ESTIMATION

First box: Traditional way to estimate the velocity (using a QEP)

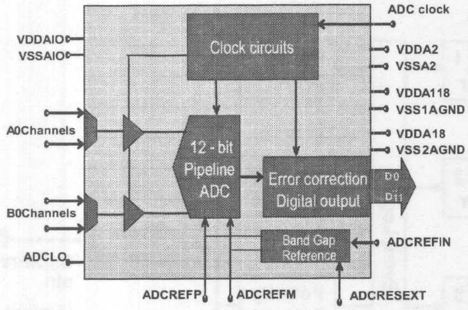
Second box: When you're moving really slow you can't use the above equation. The captures can allow you to estimate the velocity at low speeds.

Refer to App Note SPRA363 "USING THE CAPTURE UNITS FOR LOW SPEED VELOCITY ESTIMATION ON A TMS320C240" for more details



This slide shows a block diagram of the eCAP unit on the F280x controllers.

F280x Pipeline ADC module blocks



Gain internal reference = ±1.5% FSR
Gain external reference = ±1.5% FSR (less temp drift)
Offset untrimmed = ±1.5% FSR
Offset with trim = ±4LSB
DNL = ±1LSB
INL = ±1.5LSB

see datasheet for most current spec

- High-speed throughput (160 ns/6.25 MSPS)
- 12-bit resolution
- 16-channel, multiplexed inputs
- Zero wait state results
- Dual sequencers
- Simultaneous or single sampling modes
- Laser trimmed internal reference
- Register trimming dynamically removes offset
- Spec is guaranteed across full temperature range -40 to 125 C

Space available for note taking:

Digital Signal Controllers

- **Part I: Advanced motor control**
  - Advanced control overview
  - Need for a DSP
  - Optimizing systems with advanced motor control
- **Part II: TI Silicon for motor control: What's new?**
  - Available devices
  - Enhanced peripherals
  - New parts and capabilities
- **Part III: Development tools for motor control**
  - Code Composer Studio and Real time debug
  - IQ Math tools
- **Part IV: TI Software for motor control**
  - Overview of available starter code
  - Q&A

This presentation reviews advanced motor control techniques and presents new devices for motor and motion control available from Texas Instruments.

It also presents an overview of the development tools available for developing motor control algorithms with TMS320C2000 DSPs. Finally, starter code available from TI for motor control with the C2000 DSPs is presented.

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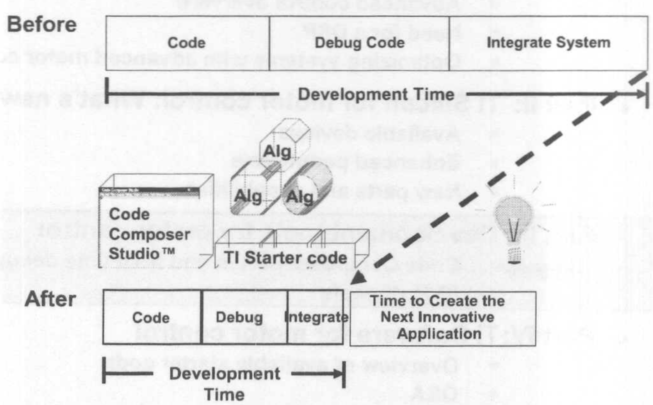
TI Foundation Software



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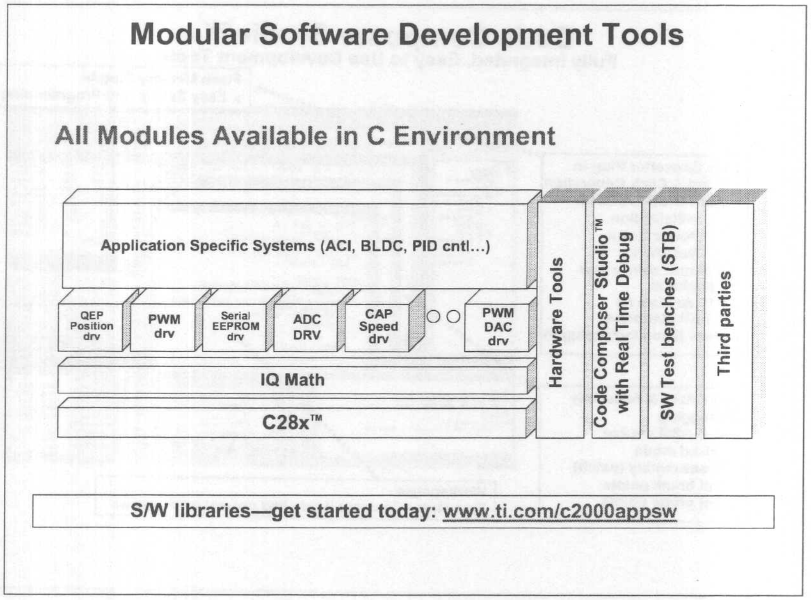

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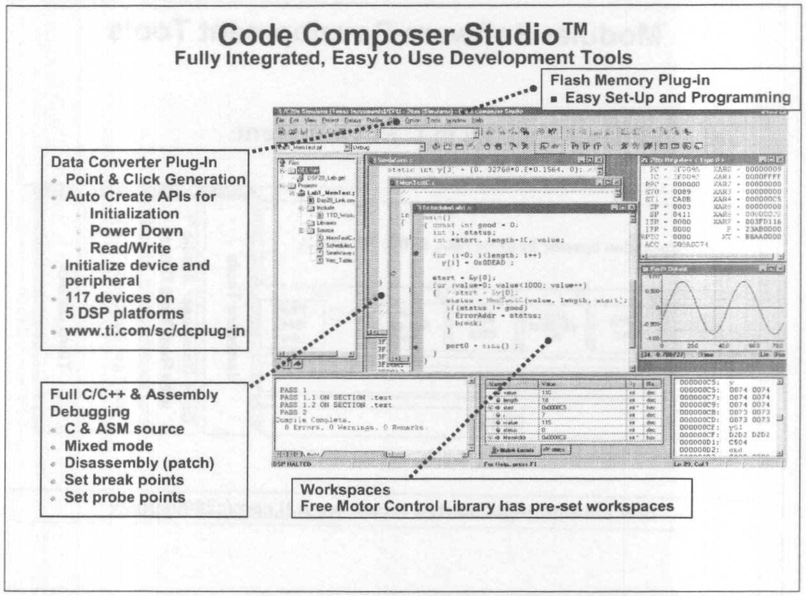
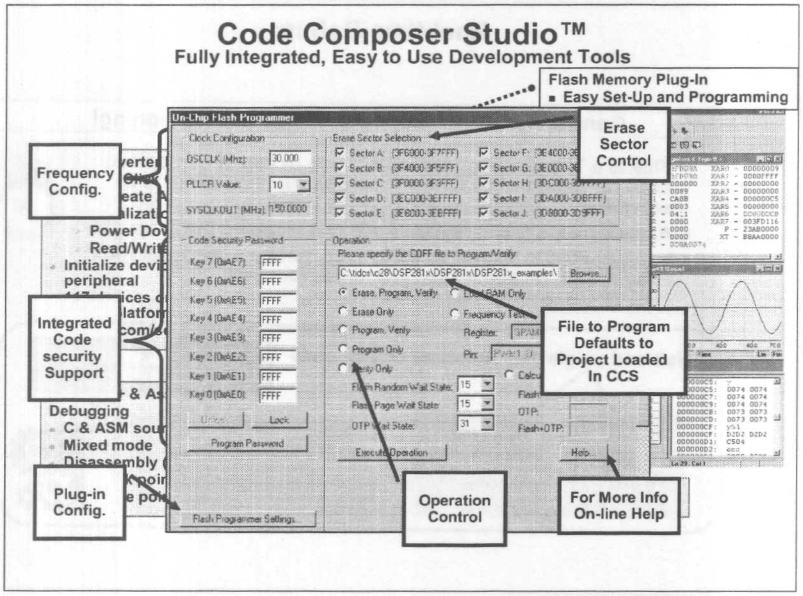
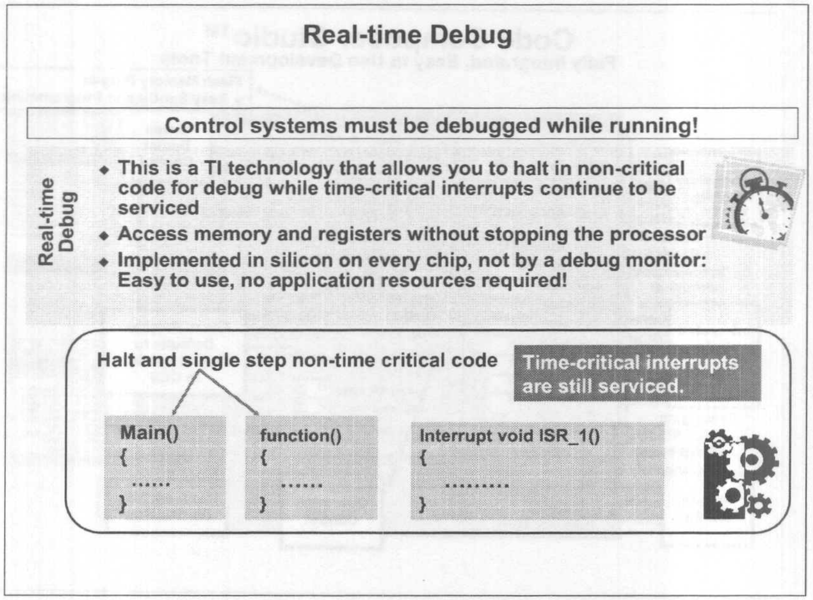


Code Composer Studio ® brings together several key elements in the code development process. These are shown in this slide.



This is a view of how tools are integrated into CCS. This is a view of the flash programming plug-in which automates flash programming and incorporates it into CCS.



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Code Composer Studio: Real time debug

Demonstration of real time debug

Digital Signal Controllers Outline

Part III: Development tools for motor control

IQ Math tools

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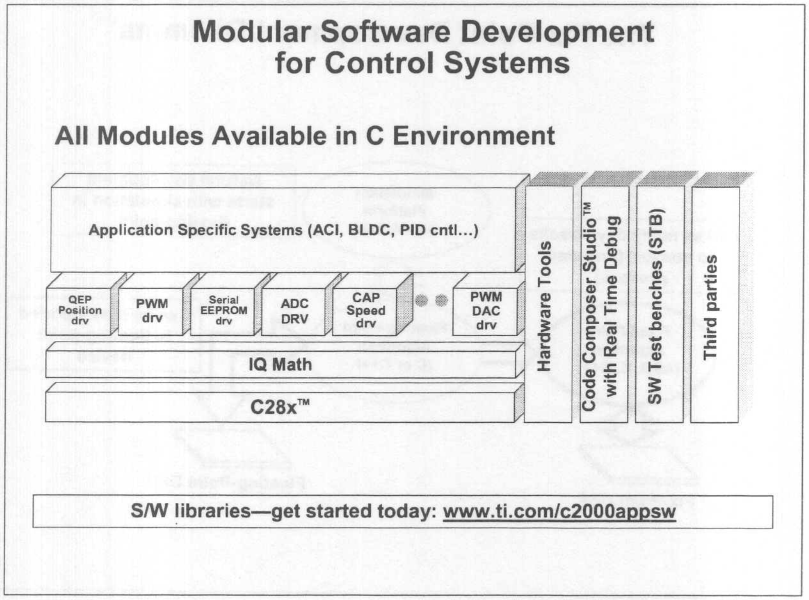

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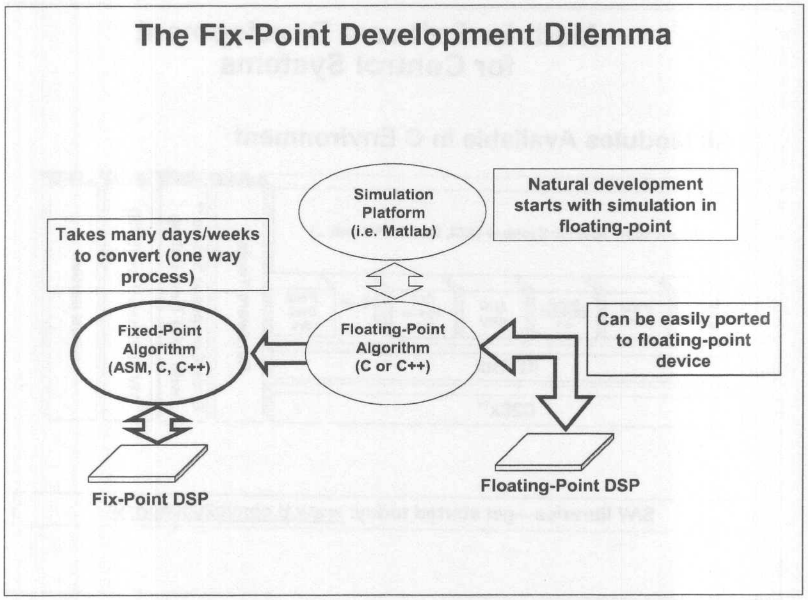

Implementing complex digital control algorithms on a Digital Signal Processor (DSP), or any other DSP capable processor, typically come across the following issues:

- Algorithms are typically developed using floating-point math
- Floating-point devices are more expensive than fixed-point devices
- Converting floating-point algorithms to a fixed-point device is very time consuming
- Conversion process is one way and therefore backward simulation is not always possible
- The diagram below illustrates a typical development scenario in use today:

The Fix The Fix-Point Development Dilemma Point Development Dilemma

The design may initially start with a simulation (i.e. Matlab) of a control algorithm, which typically would be written in floating-point math (C or C++). This algorithm can be easily ported to a floating-point device, however because of cost reasons, most likely a 16-bit or 32-bit fixed-point device would be used in many target systems.

The effort and skill involved in converting a floating-point algorithm to function using a 16-bit or 32-bit fixed-point device is quite significant. A great deal of time (many days or weeks) would be needed for reformatting, scaling and coding the problem. Additionally, the final implementation typically has little resemblance to the original algorithm. Debugging is not an easy task and the code is not easy to maintain or document.

What is "IQMath"?

"Virtual" Floating-Point Math on a 32-Bit Fixed-Point DSP (C28x)

An approach to implementing fixed point arithmetic on a DSP that enables algorithm developers to:

- Reduce mathematical algorithm implementation, porting/debugging time from hours to minutes.
- Greatly eases the scaling of numerical problems to a fixed point environment.
- This approach is suitable for algorithms where a huge dynamic range is not required. E.g. Motor Control, Audio, Modem, Telecom applications.

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IEEE Std. 754 Single Precision Floating-Point

31	30 … 23	22 … 0
s	eeeeeeee	fffffffffffffffffffffff
1 bit sign	8 bit exponent	23 bit mantissa (fraction)

Case 1: if $e = 255$ and $f \neq 0$, then $v = \text{NaN}$

Case 2: if $e = 255$ and $f = 0$, then $v = [(-1)^s]*\text{infinity}$

Case 3: if $0 < e < 255$, then $v = [(-1)^s]*[2^{(e-127)}]*(1.f)$

Case 4: if $e = 0$ and $f \neq 0$, then $v = [(-1)^s]*[2^{(-126)}]*(0.f)$

Case 5: if $e = 0$ and $f = 0$, then $v = [(-1)^s]*0$

Advantage ⇒ Exponent gives large dynamic range
Disadvantage ⇒ Precision of a number depends on its exponent

This slide shows the structure of the floating point numbers.

The large dynamic range stems from the separate exponent.

IQ Fractional Representation

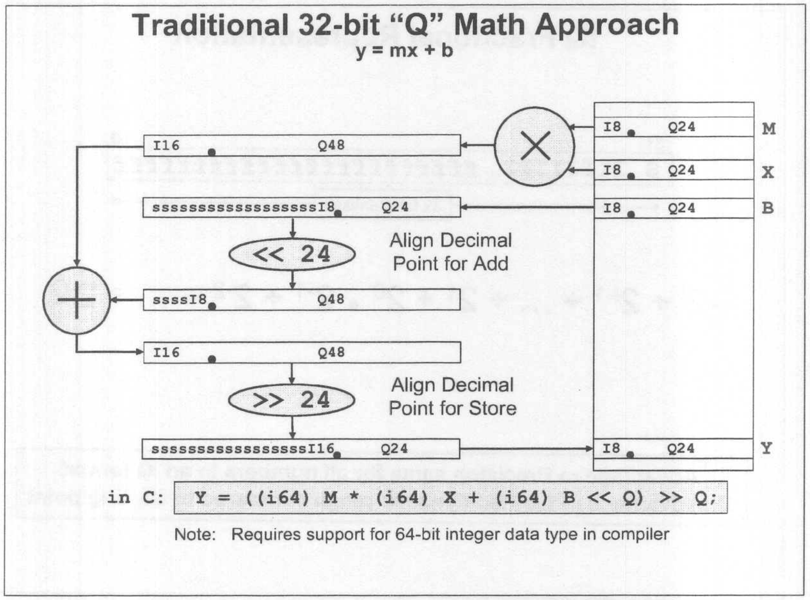
```
31                                0
S IIIIIIII . ffffffffffffffffffffff
<---------- 32 bit mantissa ---------->
```

$$-2^{I} + 2^{I-1} + \ldots + 2^{1} + 2^{0} \;\blacksquare\; 2^{-1} + 2^{-2} + \ldots + 2^{-Q}$$

Advantage ⇒ Precision same for all numbers in an IQ format
Disadvantage ⇒ Limited dynamic range compared to floating point

A new approach to fixed-point algorithm development, termed "IQmath", can greatly simplify the design development task. This approach can also be termed "virtual floating-point" since it looks like floating-point, but it is implemented using fixed-point techniques.

The IQmath approach enables the seamless portability of code between fixed and floating-point devices. This approach is applicable to many problems that do not require a large dynamic range, such as motor or digital control applications.



The traditional approach to performing math operations, using fixed-point numerical techniques can be demonstrated using a simple linear equation example. The floating-point code for a linear equation would be:

float Y, M, X, B;

Y = M * X + B;

For the fixed-point implementation, assume all data is 32-bits, and that the "Q" value, or location of the binary point, is set to 24 fractional bits (Q24). The numerical range and resolution for a 32-bit Q24 number is as follows:

The C code implementation of the linear equation is:

int32 Y, M, X, B; // numbers are all Q24

Y = ((int64) M * (int64) X + (int64) B << 24) >> 24;

Compared to the floating-point representation, it looks quite cumbersome and has little resemblance to the floating-point equation. It is obvious why programmers prefer using floating-point math.

The slide shows the implementation of the equation on a processor containing hardware that can perform a 32x32 bit multiplication, 64-bit addition and 64-bit shifts (logical and arithmetic) efficiently.

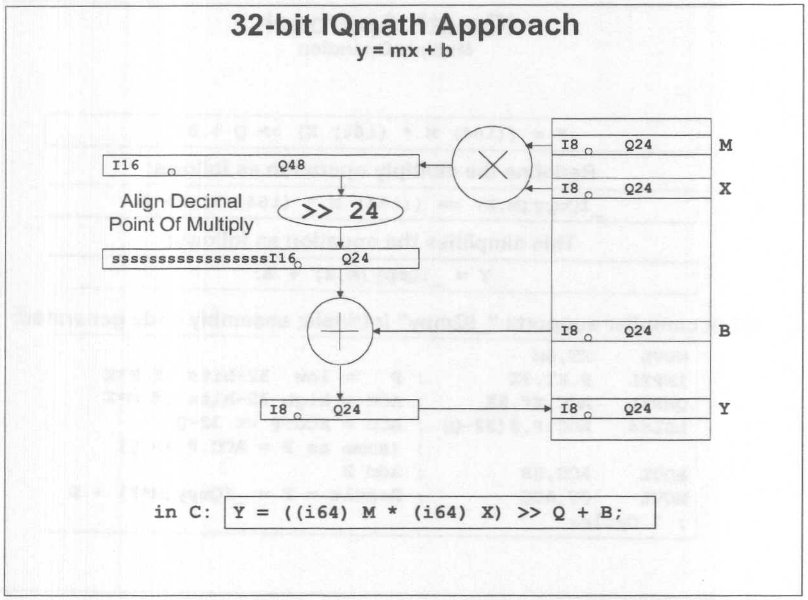
The basic approach in traditional fixed-point "Q" math is to align the binary point of the operands that get added to or subtracted from the multiplication result. As shown in the slide, the multiplication of M and X (two Q24 numbers) results in a Q48 value that is stored in a 64-bit register.

The value B (Q24) needs to be scaled to a Q48 number before addition to the M*X value (low order bits zero filled, high order bits sign extended). The final result is then scaled back to a Q24 number (arithmetic shift right) before storing into Y (Q24). Many programmers may be familiar with 16-bit fixed-point "Q" math that is in common use. The same example using 16-bit numbers with 15 fractional bits (Q15) would be coded as follows:

int16 Y, M, X, B; // numbers are all Q15

Y = ((int32) M * (int32) X + (int32) B << 15) >> 15;

In both cases, the principal methodology is the same. The binary point of the operands that get added to or subtracted from the multiplication result must be aligned.



In the "IQmath" approach, rather then scaling the operands, which get added to or subtracted from the multiplication result, we do the reverse. The multiplication result binary point is scaled back such that it aligns to the operands, which are added to or subtracted from it. The C code implementation of this is given by linear equation below:

int32 Y, M, X, B;

Y = ((int64) M * (int64) X) >> 24 + B;

The slide shows the implementation of the equation on a processor containing hardware that can perform a 32 x 32 bit multiply, 32-bit addition/subtraction and 64-bit logical and arithmetic shifts efficiently. The key advantage of this approach is shown by what can then be done with the C and C++ compiler to simplify the coding of the linear equation example. Lets take an additional step and create a multiply function in C that performs the following operation:

IQmath Approach

Multiply Operation

```
Y = ((i64) M * (i64) X) >> Q + B;
```

Redefine the multiply operation as follows:

```
_IQmpy(M,X) == ((i64) M * (i64) X) >> Q
```

This simplifies the equation as follows:

```
Y = _IQmpy(M,X) + B;
```

C28x compiler supports "_IQmpy" intrinsic; assembly code generated:

```
MOVL    XT,@M
IMPYL   P,XT,@X         ; P   = low  32-bits of M*X
QMPYL   ACC,XT,@X       ; ACC = high 32-bits of M*X
LSL64   ACC:P,#(32-Q)   ; ACC = ACC:P << 32-Q
                        ; (same as P = ACC:P >> Q)
ADDL    ACC,@B          ; Add B
MOVL    @Y,ACC          ; Result = Y = _IQmpy(M*X) + B
; 7 Cycles
```

The basic "IQmath" approach was adopted in the creation of a standard math library for the Texas Instruments TMS320C28x DSP fixed-point processor. This processor contains efficient hardware for performing 32 x 32 bit multiply, 64-bit shifts (logical and arithmetic) and 32-bit add/subtract operations, which are ideally suited for 32-bit "IQmath".

IQmath Approach

It looks like floating-point!

Floating-Point

```
float  Y, M, X, B;

Y = M * X + B;
```

Traditional Fix-Point Q

```
long Y, M, X, B;

Y = ((i64) M * (i64) X + (i64) B << Q)) >> Q;
```

"IQmath" In C

```
_iq  Y, M, X, B;

Y =  _IQmpy(M, X) + B;
```

"IQmath" In C++

```
iq  Y, M, X, B;

Y = M * X + B;
```

Taking advantage of operator overloading feature in C++, "IQmath" looks like floating-point math (looks natural!)

int32 _IQ24mpy(int32 M, int32 X) { return ((int64) M * (int64) X) >> 24; }

The linear equation can then be written as follows:

Y = _IQ24mpy(M , X) + B;

Already we can see a marked improvement in the readability of the linear equation. Using the operator overloading features of C++, we can overload the multiplication operand "*" such that when a particular data type is encountered, it will automatically implement the scaled multiply operation. Lets define a data type called "iq" and assign the linear variables to this data type:

iq Y, M, X, B // numbers are all Q24

The overloading of the multiply operand in C++ can be defined as follows:

iq operator * (const iq &M, const iq &X) { return ((int64) M * (int64) X) >> 24; }

Then the linear equation, in C++, becomes:

Y = M * X + B;

This final equation looks identical to the floating-point representation. It looks "natural". The four approaches are summarized on the next page:

Math Implementations Linear Equation Code

32-bit floating-point math in C: Y = M * X + B;

32-bit fixed-point "Q" math in C: Y = ((int64) M * (int64) X) + (int64) B << 24) >> 24;

32-bit IQmath in C: Y = _IQ24mpy(M, X) + B;

32-bit IQmath in C++: Y = M * X + B;

Essentially, the mathematical approach of scaling the multiplier operand enables a cleaner and a more "natural" approach to coding fixed-point problems. For want of a better term, we call this approach "IQmath" or can also be described as "virtual floating-point".

Some enhancements were made to the basic "IQmath" approach to improve flexibility. They are:

Setting Of GLOBAL_Q Parameter Value: Depending on the application, the amount of numerical resolution or dynamic range required may vary. In the linear equation example, we used a Q value of 24 (Q24). There is no reason why any value of Q can't be used. In the "IQmath" library, the user can set a GLOBAL_Q parameter, with a range of 1 to 30 (Q1 to Q30). All functions used in the program will use this GLOBAL_Q value.

For example:

#define GLOBAL_Q 18

Y = _IQmpy(M, X) + B; // all values use GLOBAL_Q = 18

If, for some reason a particular function or equation requires a different resolution, then the user has the option to implicitly specify the Q value for the operation. For example:

Y = _IQ23mpy(M,X) + B; // all values use Q23, including B and Y

The Q value must be consistent for all expressions in the same line of code.

IQ Math Platform Requirements

To be practical, IQ math needs:

- **A 32-bit DSP for implementation.**
- **An intelligent compiler to generate optimal code**

TI C28x DSP meets these requirements and implements IQ math efficiently

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AC Induction Motor Example

Park Transform - converting to "IQmath" C code

```
#include  "IQmathLib.h"

#define  TWO_PI   _IQ(6.28318530717959)
void park_calc(PARK *v)
{
   _iq   cos_ang , sin_ang;
    sin_ang = _IQsin(_IQmpy(TWO_PI , v->ang));
    cos_ang = _IQcos(_IQmpy(TWO_PI , v->ang));

    v->de =    _IQmpy(v->ds , cos_ang) + _IQmpy(v->qs , sin_ang);
    v->qe =    _IQmpy(v->qs , cos_ang) - _IQmpy(v->ds , sin_ang);
}
```

This slide animates to show how the code converts over. If printed, the final converted code is shown. A comparison to the previous slide shows the changes.

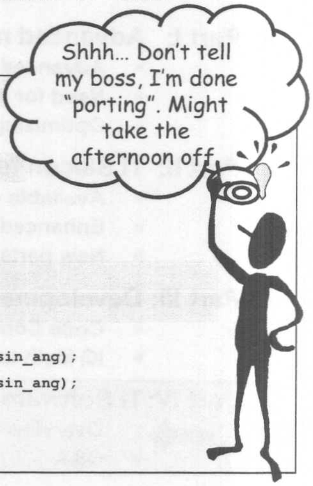
AC Induction Motor Example

Park Transform - converting to "IQmath" C++ code

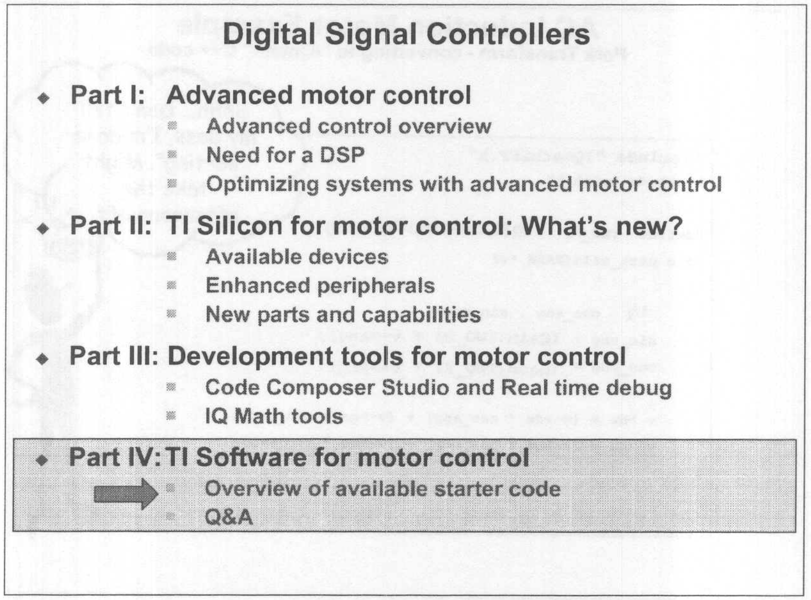
```
#include "IQmathCPP.h"
#include "math.h"

#define  TWO_PI    IQ(6.28318530717959)
void park_calc(PARK *v)
{
      iq   cos_ang , sin_ang;
      sin_ang = IQsin(TWO_PI * v->ang);
      cos_ang = IQcos(TWO_PI * v->ang);

      v->de = (v->ds * cos_ang) + (v->qs * sin_ang);
      v->qe = (v->qs * cos_ang) - (v->ds * sin_ang);
}
```



This slide shows how to convert code over to the C++ version.

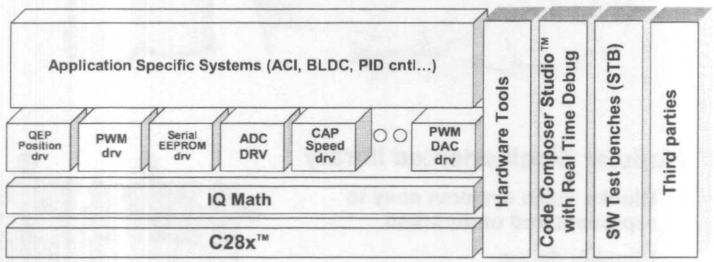


This presentation reviews advanced motor control techniques and presents new devices for motor and motion control available from Texas Instruments.

It also presents an overview of the development tools available for developing motor control algorithms with TMS320C2000 DSPs. Finally, starter code available from TI for motor control with the C2000 DSPs is presented.

The goal today is to familiarize the audience with some of the advanced motor control techniques, and review some of the collateral available to get designs done rapidly.

Modular Software Development for Control Systems



S/W libraries—get started today: www.ti.com/c2000appsw

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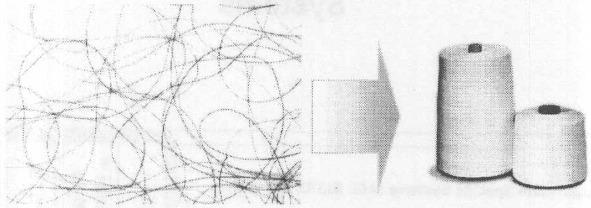
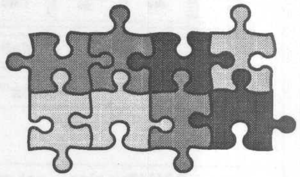


Modular Block oriented library

- Blocks make systems easy to represent and understand
- Simplify debug
- Enable incremental deployment



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Incremental System Build

- Incremental system development/debug is built in
- Incremental system development/debug relies on modular software blocks
- Incremental system development/debug is flexible/systematic
- Incremental system development/debug applies to multiple processors, drives and motors

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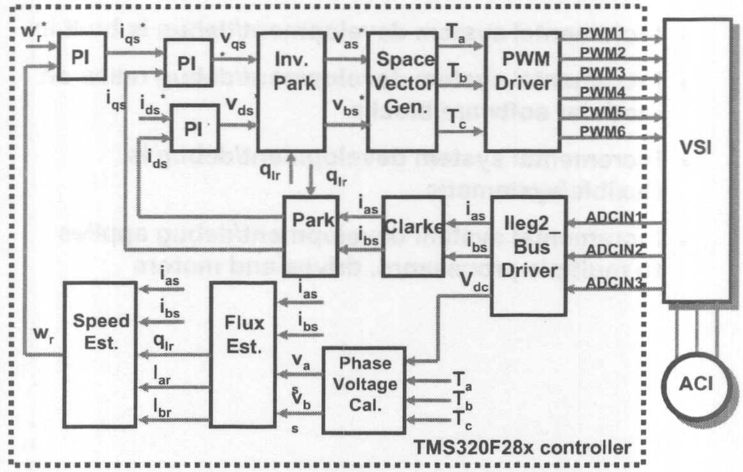
Ex: ACI Sensorless Field Oriented Control



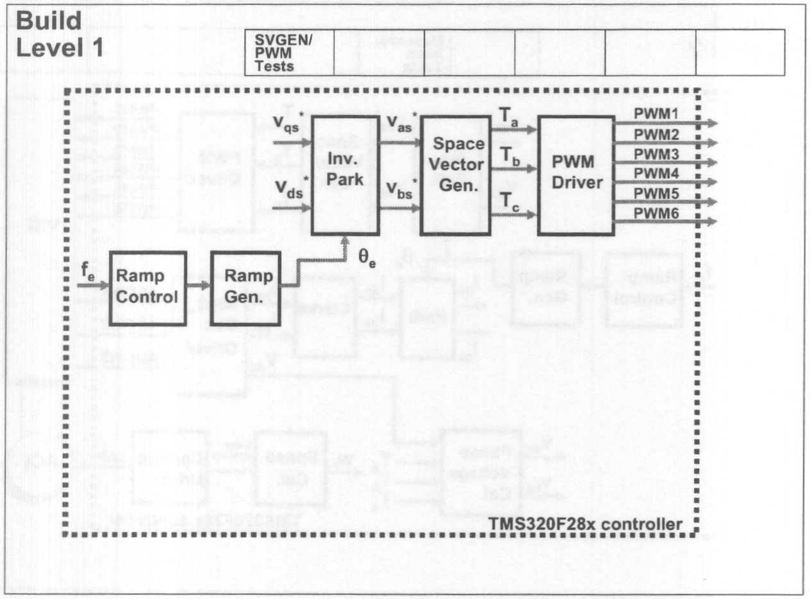
Here is a block diagram of a sensorless motor drive system showing the motor control related functions.

If this system were given to you, what would be the first thing you would have to start doing?

You could go for broke, and try it, but based on most peoples experience, the chances of a complex system working directly (unassisted) on new hardware are small.

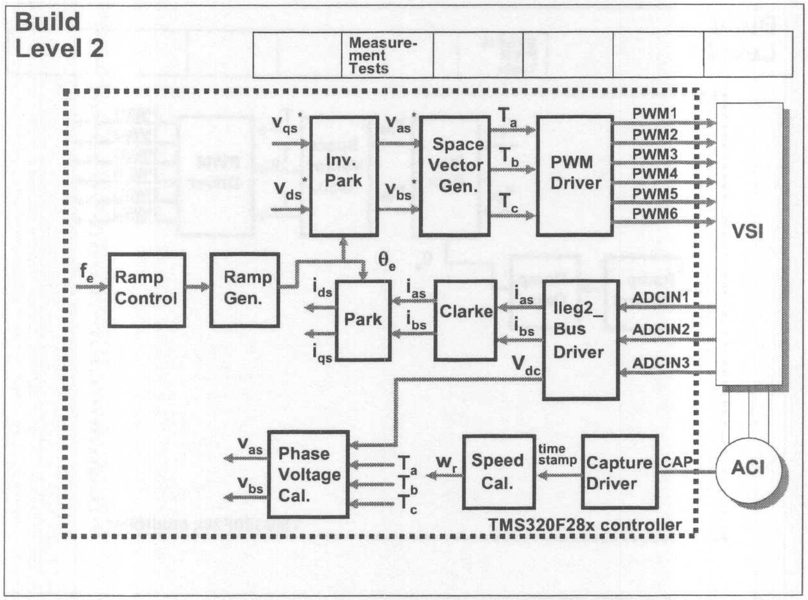
The first thing would probably be to start inserting test code in the system to activate the PWM, and then the ADC and so on in a specific order, so that you could build up the system in a logical order of functions.

What if this were already done for you? TI has built in precisely this function into a incremental build infrastructure to facilitate deploying TI application examples in <u>your</u> application environment.



Here is a build level 1: All it does is it runs a space vector modulation scheme to output modulated PWM out of the PWM pins on the F28x DSP controller.

Elementary as it seems this constitutes an important step: You are now successfully loading and running a real time application that runs a periodic task, and computes PWM command values in real time and updates the PWM registers. Once you have Build 1 running, you should be able to test your hardware, test PWM polarities and inverter signals.



Once you have build 1 running the motor can be run open loop – since there exists enough drive waveforms to stimulate a 3 phase ACI. Once you can do that the next step is to measure currents in the motor windings. Build 2 accomplishes this, and allows you to build one more step onto running the entire system.

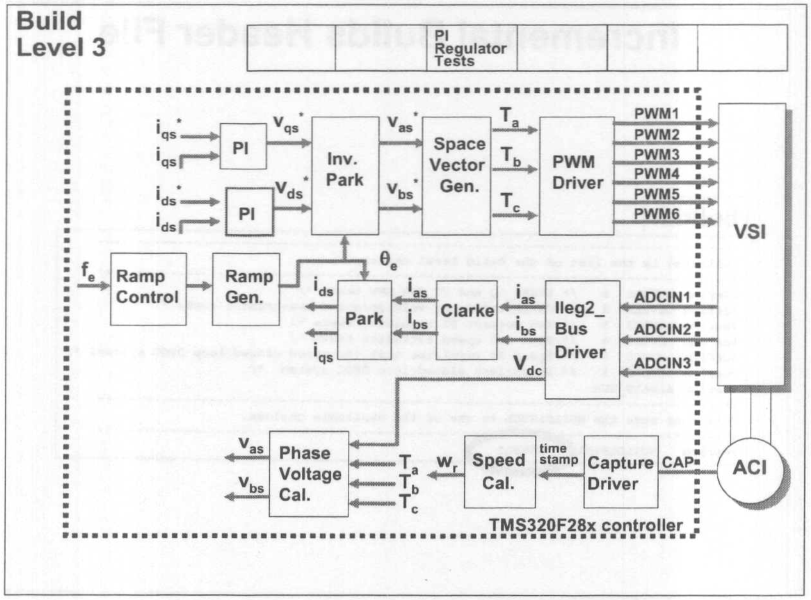
Incremental Builds Header File

build.h

```
/*------------------------------------------------------------------------------
Following is the list of the Build Level choices.
------------------------------------------------------------------------------*/
#define LEVEL1  1   /* SVGEN_DQ and FC_PWM_DRV tests */
#define LEVEL2  2   /* Currents/DC-bus voltage/speed measurement tests */
#define LEVEL3  3   /* Two current PI regulator tests */
#define LEVEL4  4   /* Flux and speed estimator tests */
#define LEVEL5  5   /* Speed PI regulator test (Sensored closed-loop DFOC system) */
#define LEVEL6  6   /* Sensorless closed-loop DFOC system  */
#define ALWAYS_RUN
/*------------------------------------------------------------------------------
This line sets the BUILDLEVEL to one of the available choices.
------------------------------------------------------------------------------*/
#define   BUILDLEVEL    LEVEL3
```

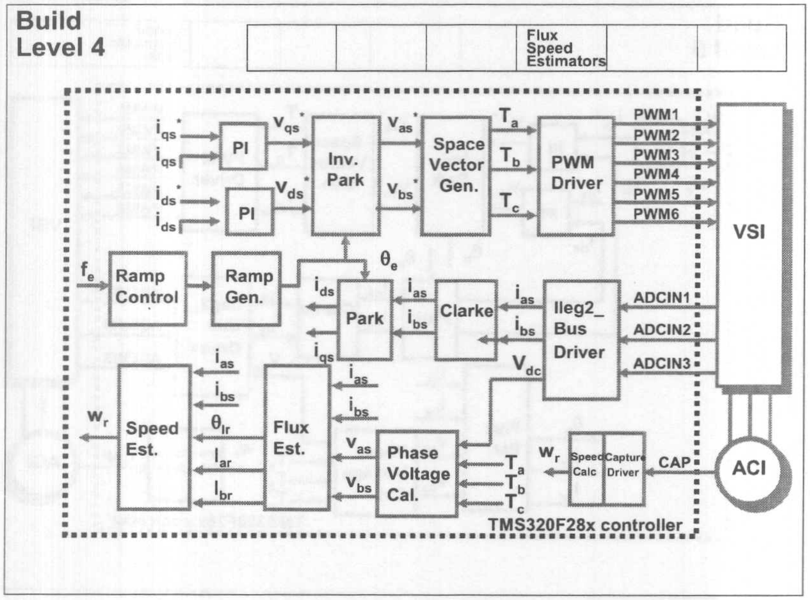
So, how do you change from one build level to another?

Changing from one build level to another is accomplished via conditional compilation, controlled by a 'BUILDLEVEL' constant. This constant is controlled in a file called "build.h". This file is included from the client application pulling in the build level setting. Changing from one build level to another is very simple: You just change the level the BUILDLEVEL is set to.

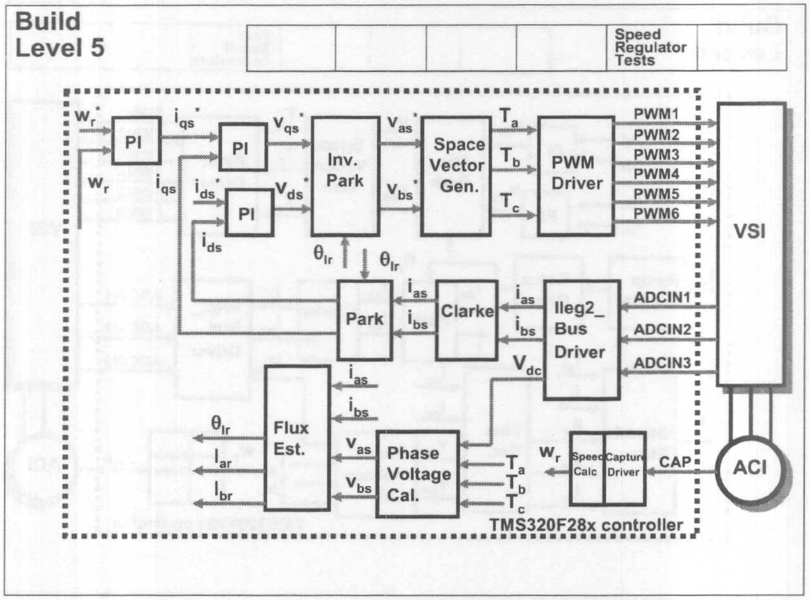


The BUILDLEVEL 3 adds the current PI regulators.

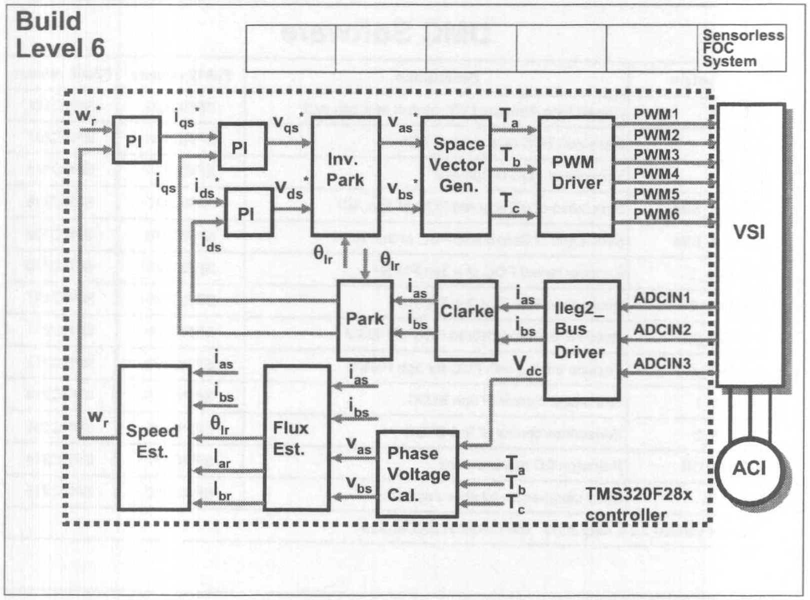
Digital Motor Control



The BUILDLEVEL 4 adds the speed and flux estimation.



The BUILDLEVEL 5 adds the a speed PI regulator and tests it on the basis of a speed sensor.



Level 6 runs the entire system, and at this point all the functional blocks are implemented in the system.

DMC Software

System	Description	F2812 release	F2808 release
ACI3_1	Closed loop Sensored V/F control of a 3ph ACI.	SPRC130	SPRC194
ACI3_3	Sensored FOC of a 3 phase ACI	SPRC216	SPRC207
ACI3_4	Sensorless FOC of 3ph ACI	SPRC079	SPRC195
ACI3_3_SIM	Simulation of a Sensored FOC of 3ph ACI	SPRC077	SPRC208
ACI3_4_SIM	Simulation of Sensorless FOC of 3ph ACI	SPRC078	SPRC209
PMSM3_1	Encoder based FOC of a 3ph PMSM	SPRC129	SPRC210
PMSM3_2	Sensorless FOC of a 3ph PMSM.	SPRC128	SPRC197
PMSM3_3	Resolver based sensored FOC of PMSM.	SPRC178	SPRC211
PMSM3_4	Position control with FOC for 3ph PMSM.	SPRC179	SPRC212
BLDC3_1	Hall based control of 3ph BLDC	SPRC175	SPRC213
BLDC3_2	Sensorless control of 3ph BLDC	SRPC176	SPRC196
DCMOTOR	Precision DC motor control	SPRC177	SPRC214
DMCLIB	Base Libraries for all above systems.	SPRC080	SPRC215
Current version 3.21, May 2005 www.ti.com/c2000appsw			

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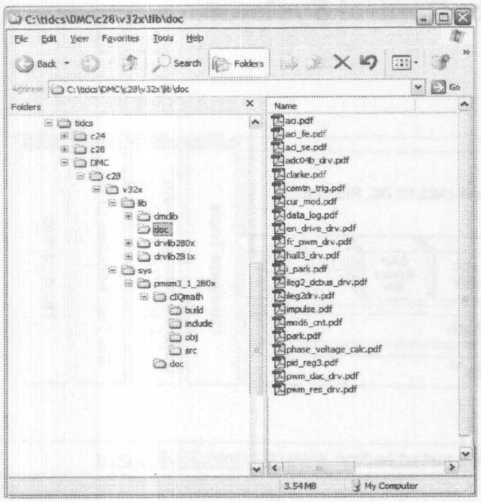
DMC Software



DMC SW Includes:

- Source
- Documentation
- Incremental builds
- All base libraries
- DSP28 header files

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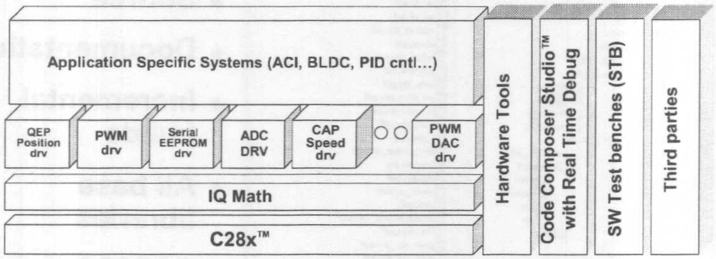
Modular Software Development for Control Systems



S/W libraries—get started today: www.ti.com/c2000appsw

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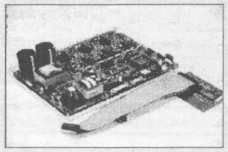
Hardware Development Tools

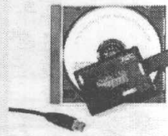
eZdsp Kits

- **LF2407A, LF2401A, F2812, and F2808 eZdsp board**
- **Compiler/Asm/Linker**
- **Code Composer Studio (only works with eZdsp)**
- **Power Supply**
- **USB or Serial**
- Price: $345 - $595



Power Modules

- **DMC550 or DMC1500 from Spectrum Digital Interfaces to EVM, eZdsp or standalone operation**
- **Protection features provide convenient s/w development platform**
- **DMC1500: 350V 7.5A (1&3 ph; BLDC, ACI, SR) $1749**
- **DMC500: 24V 2.5A (BLDC) $499**



Bundles

- **F28xx eZdsp or LF2407 EVM**
- **USB or PP+ Emulator**
- **Unrestricted version of Code Composer Studio**
- **Bundles: $1995 - $2295**
- **Emulators: $1500-$1995 (if purchased separately)**

http://www.ti.com/c2000hwtools

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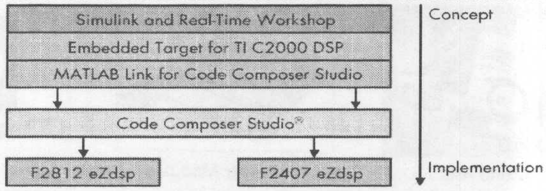
Embedded Target Integrates Simulink® and MATLAB® with eXpressDSP™ Tools and C2000™ Controllers



Key Features

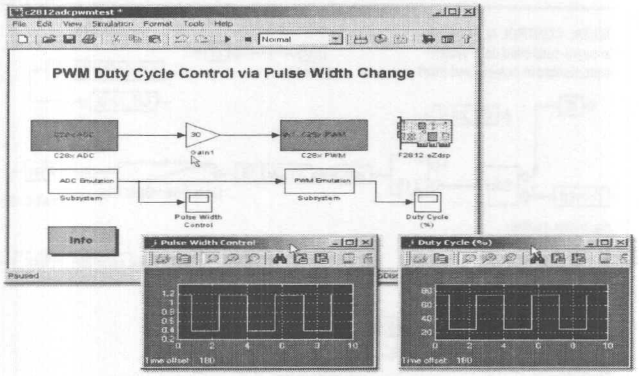
- **Design and Simulation**
- **Automatic code generation**
  - **Embedded Target for C2000**
  - **Documentation, re-usable C code**
  - **Support for on-chip peripherals**
- **Verification of embedded implementation**
  - **MATLAB Link for Code Composer Studio**
  - **Auto debug, testbench**
  - **Real-time visualization**

http://www.ti.com/c2000embeddedtarget

F2808 support for Embedded Target for C2000 will be available in Dec. 2005.

Space available for note taking:

Embedded Target Integrates Simulink® and MATLAB® with eXpressDSP™ Tools and C2000™ Controllers



http://www.ti.com/c2000embeddedtarget

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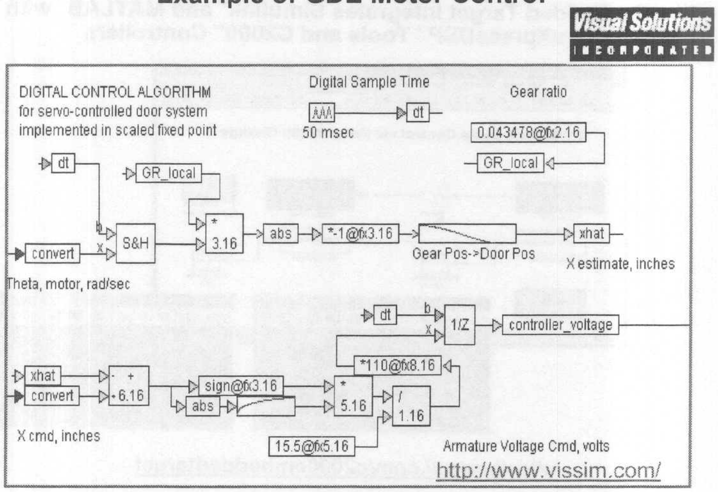
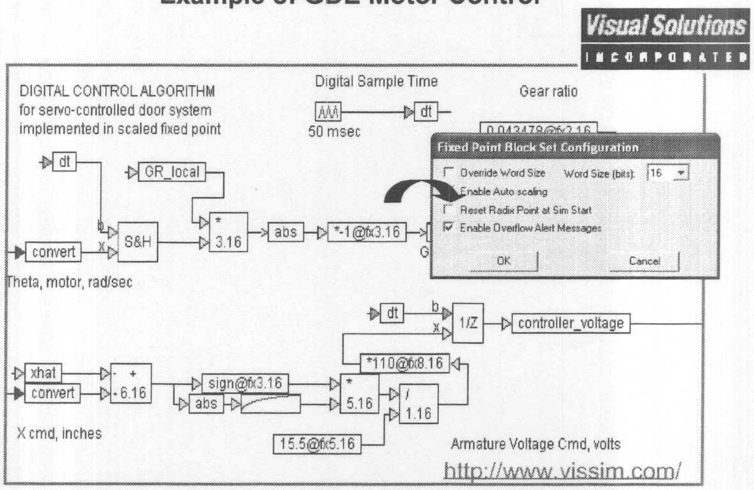
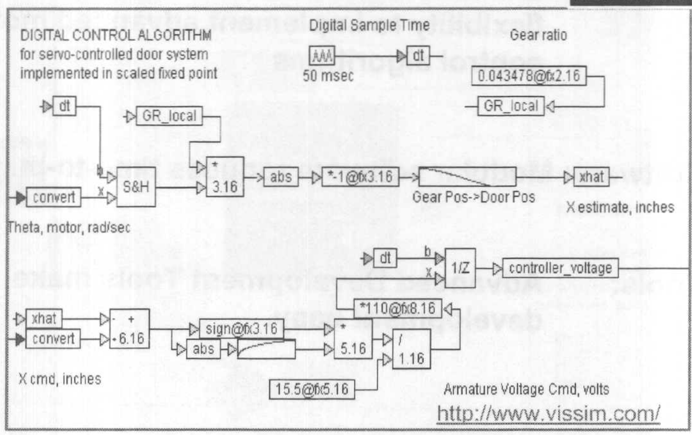
Example of GDE Motor Control



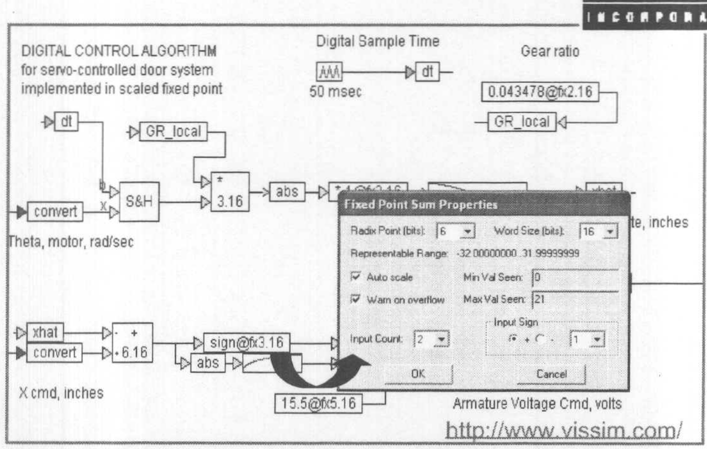
Example of GDE Motor Control



Example of GDE Motor Control



Example of GDE Motor Control



Silicon: **DSP offers the performance and flexibility to implement advanced motor control algorithms**

Software: **Modular software reduces time-to-market**

Tools: **Advanced Development Tools make development easy.**

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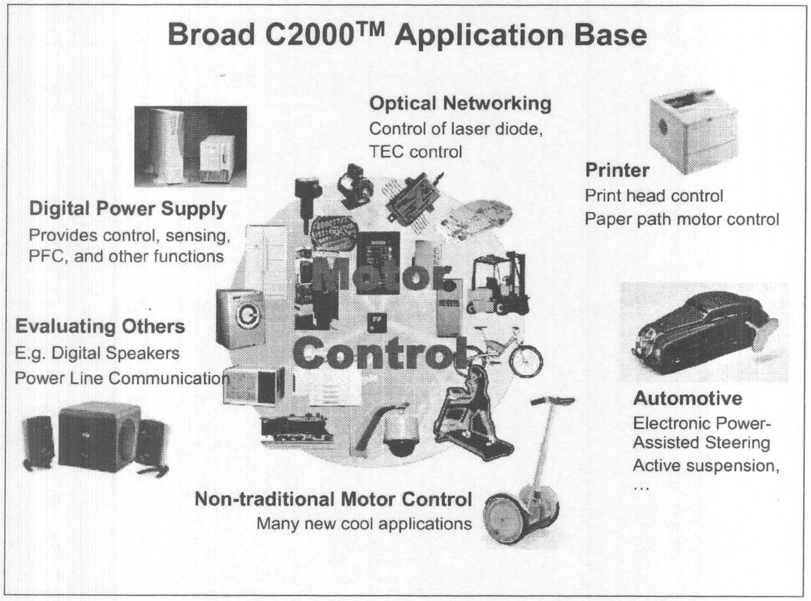

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Texas Instruments

High Performance Signal Chain For Motor Control

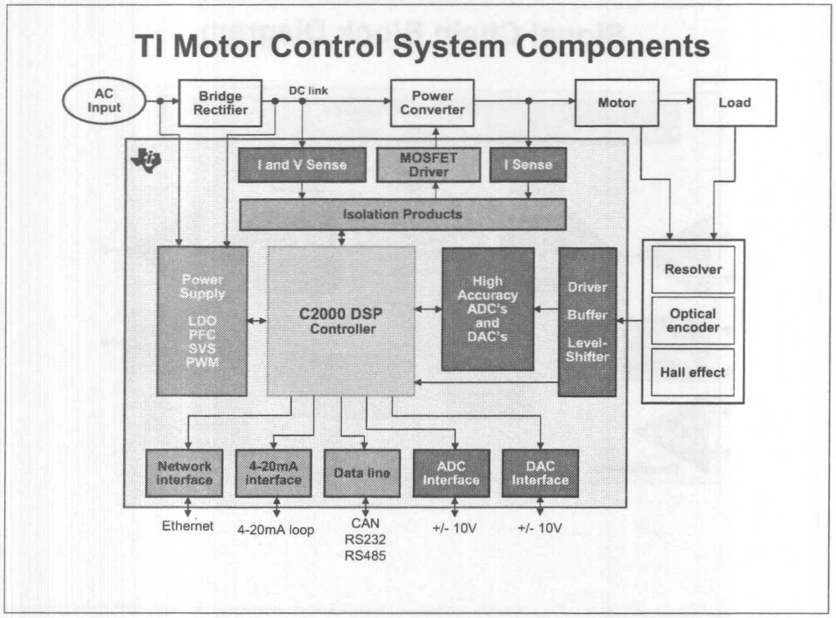
High Performance Analog Outline

- **Part I: Signal Chain Overview**
  - Accuracy vs. Resolution
  - Datasheet and Reference Voltage Concerns
- **Part II: Data Converter Drive Concerns**
  - Low Voltage Drive to Embedded ADC
  - High Voltage (±10V) Interface to ADC and DAC
- **Part III: Analog Front End for Motor Control**
  - Interfacing Sine/Cosine Encoder
  - Complete High Accuracy DMC Solution
- **Part IV: Current Measurement Options**
  - Delta-Sigma Modulator Solutions
  - Current Shunt Monitors
  - Isolation Solutions
- **Part V: Tools for High Performance Analog**

Part I: Signal Chain Overview

The analog signal chain to a motor control system includes power management, input and output signal conditioning for control and monitor functions, input sensor signal conditioning and power drive components. Our main focus in this section will be on the factors that drive the accuracy of a digital motor control system.

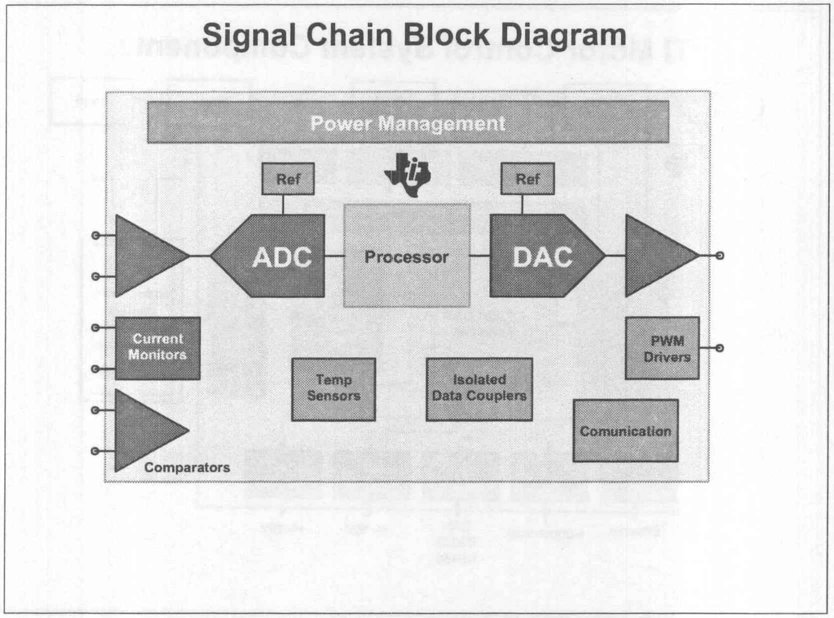
Part I of our presentation will explain the differences between accuracy and resolution as well as compare the typical performance characteristics of internal and external data converters found in DMC Host Processors. We will also look at ways to improve the accuracy of the internal converter by using an external precision voltage reference.



This slide depicts the wide variety of components available from Texas Instruments for the implementation of a Digital Motion Control system.

With the C2000 family of Digital Signal Processors (DSP), Texas Instruments can provide a complete "system on a chip" solution for low cost systems. Texas Instruments also has the capability to provide "one stop shopping" for external peripherals used in signal conditioning, high accuracy data acquisition, isolation products, current shunt and DC Link voltage monitoring, power supply and supervisory circuits as well as human interface products such as RS232 and CAN transceivers.

The heart of the system as shown above is the C2000 DSP Controller. The shaded boxes around the DSP represent all the associated components found within a typical DMC system. With such a diverse portfolio of products to choose from, Texas Instruments and Burr-Brown Products from Texas Instruments can provide solutions to the most demanding application.



Signal Chain Block Diagram:

The Signal Chain for digital motor control includes the analog input, analog to digital conversion (ADC), signal processing, digital to analog conversion (DAC) and analog output.

Analog Input:

In most cases, some sort of signal conditioning is required on the input side of the controller. Applied signals from sensors, encoders, resolvers or even the input command signal often require filtering and or gain of some sort before they can be digitized by the data converter. Throughout this presentation, we will present a variety of circuits that can be applied to the internal data converter of the DM controller or stand alone ADC's.

ADC:

The resolution and accuracy requirements of the system will be the largest factors driving the choice of the ADC. We will take a look at data sheet specifications to identify which parameters affect the overall accuracy of the system, allowing the designer to determine if the internal data converter on the host processor suits the requirements of the design.

Processor:

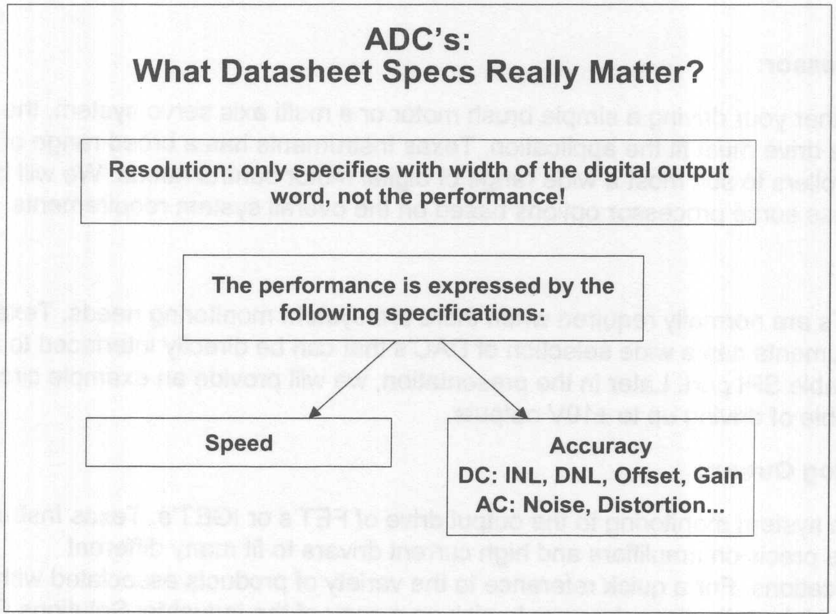
Whether your driving a simple brush motor or a multi axis servo system, the brain of the drive must fit the application. Texas Instruments has a broad range of digital controllers to suit most a wide range of digital motor control needs. We will briefly discuss some processor options based on the overall system requirements.

DAC:

DAC's are normally required when there are system monitoring needs. Texas Instruments has a wide selection of DAC's that can be directly interfaced to any available SPI port. Later in the presentation, we will provide an example circuit capable of driving up to ±10V outputs.

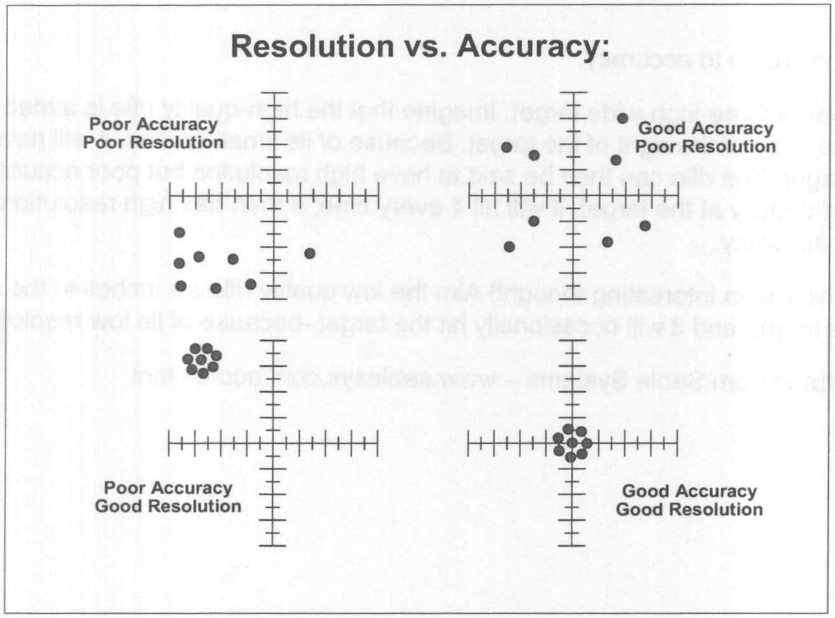
Analog Output:

From system monitoring to the output drive of FET's or IGBT's, Texas Instruments offers precision amplifiers and high current drivers to fit many different applications. For a quick reference to the variety of products associated with industrial applications, be sure to pick up a copy of the Industrial Solutions Guide (TI Doc #SLAB039) or download a copy from the Data Converter home page found at ANALOG.TI.COM



Demystifying Data Sheet Specifications:

Lets turn our attention to a few ADC specifications found in typical datasheets. To start off this section, we'll have a little discussion on the differences between resolution and accuracy.



There is a distinct difference between resolution and accuracy.

The targets above provide a sporting analogy.

You have two rifles – a high quality one and a low quality one. The high quality one is manufactured to shoot with a small "spread" – in other words, several bullets fired from the high-quality rifle will land within a small distance of each other, perhaps within a 1″ circle. The low quality rifle will have a larger "spread" – for example, a 10″ diameter area within which rounds that are fired at a single target will land.

Obviously, it's easier to tell where a bullet from the high quality rifle was supposed to land. Using the high quality rifle, you can distinguish targets as close as an inch or two apart. The low quality rifle, with its larger "spread", would generate a scatter of shots over the whole area being targeted.

The high quality rifle has high resolution. It can be aimed at targets only a small distance apart. The low quality rifle has low resolution. It can be used for firing at the general area of a target, but if you need to distinguish between separate small targets it won't do the job.

Let's move on to accuracy.

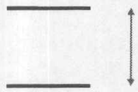
Imagine a three-inch-wide target. Imagine that the high-quality rifle is aimed six inches or so to the right of the target. Because of its small spread, it will never hit the target. The rifle can then be said to have high resolution but poor accuracy. If aimed directly at the target, it will hit it every time; it then has high resolution and good accuracy.

Now here's an interesting thought! Aim the low quality rifle six inches to the right of the target, and it will occasionally hit the target -because of its low resolution.

Excerpted from Sable Systems – www.sablesys.com/accres.htnl

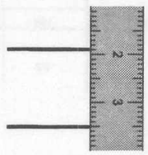
Resolution vs. Accuracy: Ruler Example

If I draw two lines, and say they are 1 inch apart:



If I divide this into more lines, I have more resolution:

But in either case, I may not be accurate, because the distance may not really be 1 inch. To know that, I must compare it to a ruler – a REFERENCE for measuring distances.



Hmm... doesn't look too accurate

The ruler example of resolution versus accuracy is another simple way to visualize the difference between the terms and brings in another important aspect. The Reference – as applied in the particular case of data conversion, can be the single biggest factor regarding the accuracy of the DMC. We'll take a closer look at voltage references a little later in the presentation.

Most Important Parameters

Parameters		ADS7829 Typ	ADS7829 Max	ADS7866 Typ	ADS7866 Max	56F807 Typ	56F807 Max	F2808 Typ	F2808 Max
Speed	kSPS		125		200		714*		6250
Res.	bits	12		12		12		12	
INL	LSB	±0.4	±1.25	±1.0	±1.5	±2.5	±4	_	±1.5
DNL	LSB	±0.4	-1.25	±0.8	-1.5	±0.9	±1	_	±1.0
Offset	mV	±0.18	±1.83	±0.5	±0.87	-25	+10/-90	_	±43.9*
Gain	%FSR	±0.007	±0.05	±0.007	±0.05	0	+8/-7	_	±1.46

***The F2808 has internal offset compensation which compensates for the offset. With compensation applied, the offset drops to ±4 LSB or ±2.92mV.**

ELECTRICAL CHARACTERISTICS

Over recommended operating free-air temperature range at –40°C to 85°C, AV_{DD} = 5V, BV_{DD} = 3V, V_{REF} = internal +2.5V, f_{CLK} = 10MHz, and f_{SAMPLE} = 500 kSPS, unless otherwise noted

PARAMETER	CONDITIONS	ADS8361 MIN	ADS8361 TYP(1)	ADS8361 MAX	UNITS
ANALOG INPUT					
Full-Scale Range(2) (FSR)	+IN – (–IN)			$\pm V_{REF}$	V
Operating Common-Mode Signal		2.2		2.8	V
Input Switch Resistance	–IN = V_{REF}		20		Ω
Input Capacitance	–IN = V_{REF}		25		pF

TI offers a wide variety of analog to digital converters for digital motor control and industrial data acquisition. The converter speed is normally listed in the Sampling Dynamics section of the product datasheet. The speed is referred to as the Throughput Rate of the converter. The throughput or sample rate of the converter found on theTMS320F2808 is 6.25 mega-samples per second (MSPS)! External data converter devices like the ADS8361 and ADS7869 have throughput rates of 500kSPS and 1MSPS is 100kHz and 500kHz, respectively.

The Resolution of the converter is listed under the System Performance of section of the specifications table. The resolution of a A/D is specified in bits. It is the number distinct 2^N codes the converter is capable of producing over the full range. The resolution of the converter doesn't indicate the accuracy of the A/D. We'll talk more about this later. The table above compares the 12-bit ADC found in an embedded processor compared to external stand alone devices.

After we look at speed, we consider a few DC performance "yard stick's" (remember the ruler example?). DC parameters are primarily Integral Non-linearity, Differential Non-Linearity, offset errors and gain errors.

What should you look for?

ADC's performance over temperature at specified speed

Insured values based on tests in production

Clear test conditions for specified parameters

No hidden and unclear limitations

ELECTRICAL CHARACTERISTICS

Over recommended operating free-air temperature range at –40°C to 85°C, AV_{DD} = 5V, BV_{DD} = 3V, V_{REF} = internal +2.5V, f_{CLK} = 10MHz, and f_{SAMPLE} = 500 kSPS, unless otherwise noted.

PARAMETER		CONDITIONS	ADS8361 MIN	TYP(1)	MAX	UNITS
ANALOG INPUT						
Full-Scale Range(2)	(FSR)	+IN – (–IN)			$\pm V_{REF}$	V
Operating Common-Mode Signal			2.2		2.8	V
Input Switch Resistance		$-IN = V_{REF}$		20		Ω
Input Capacitance		$-IN = V_{REF}$		25		pF
Input Leakage Current		$-IN = V_{REF}$		±1		nA
Differential Input Switch Resistance				40		Ω
Differential Input Capacitance				15		pF
Common-Mode Rejection Ratio	(CMRR)	At DC		84		dB
		V_{IN} = ±1.25Vp-p at 50kHz		80		dB
DC ACCURACY						
Resolution			16			Bits
No Missing Code	(NMC)		14			Bits
Integral Linearity Error	(INL)			±3	±8	LSB(3)
Integral Linearity Match		Channel 0/1, Same A/D		4		LSB
Differential Nonlinearity	(DNL)			+1.5(4)		LSB
Bipolar Offset Error	(V_{OS})			±0.5	±2	mV
Bipolar Offset Error Match		Channel 0/1, Same A/D		0.5	1	mV
Bipolar Offset Error Drift	(TCV_{OS})			0.4		ppm/°C
Gain Error(6)	(G_{ERR})			±0.05	±0.5	%
Gain Error Match				0.05	0.15	%
Gain Error Drift	(TCG_{ERR})			20		ppm/°C
Noise				60		µVrms
Power-Supply Rejection Ratio	(PSRR)	4.75V < AV_{DD} < 5.25V, with External Reference, at DC		–70		dB
SAMPLING DYNAMICS						
Conversion Time per A/D	(t_{CONV})	100kHz ≤ f_{CLK} ≤ 10MHz	1.6		160	µs
Acquisition Time	(t_{AQ})	f_{CLK} = 10MHz	400			ns
Throughout Rate					500	kSPS

NOTES: (1) All Values are at T_A = 25°C. (2) Ideal input span; does not include gain or offset error. (3) LSB means Least Significant Bit, with V_{REF} equal to +2.5V; 1LSB = 76µV. (4) Specified for 14-bit no missing code. (5) Specified for 15-bit no missing code. (6) Measured relative to an ideal, full-scale input (+IN – (–IN)) of 4.9999V. Thus, gain error does not include the error of the internal voltage reference.

What should you look for when evaluating the specification of an ADC (or any component for that matter)? First, be sure the test conditions listed in the datasheet cover the operating conditions of the end system. Ideally, a 500kSPS data converter like the ADS8361 shown above, has specifications based on the full operating speed. As a general rule – applications which use the converter at slower than rated speed will see an increase in performance.

Another very important item on a datasheet is the minimum, typical and maximum specifications. Test's which only list typical values should be carefully scrutanized. In most cases, it is not advisable to use a typical value when trying to determine if a component will fit the application. Why? Because typical values are not production tested! Tests which list MIN and/or MAX values imply that EVERY component will fall withing a specific window that is verified at production test.

Be sure the test conditions are clearly defined. There is no way to verify a particular specification in the end system if the datasheet does not reveal how the test was conducted. Also, be sure that any note regarding a specific test does not place undo restrictions on the device.

What You Do Not Want to See:

Table 35. ADC Characteristics

Operating Conditions: $V_{SS} = V_{SSA} = 0$ V, $V_{DD} = V_{DDA} = 3.0–3.6$ V, $V_{REF} = V_{DD}-0.3$V, ADCDIV = 4, 9, or 14, (for optimal performance). ADC clock = 4MHz, 3.0–3.6 V, $T_A = -40°$ to +85°C, $C_L \leq 50$pF, $f_{OP} = 80$MHz

Characteristic	Symbol	Min	Typ	Max	Unit
ADC input voltages	V_{ADCIN}	0^1	—	$V_{REF}{}^2$	V
Resolution	R_{ES}	12	—	12	Bits
Integral Non-Linearity[3]	INL	—	+/- 2.5	+/- 4	LSB[4]
Differential Non-Linearity	DNL	—	+/- 0.9	+/- 1	LSB[4]
Monotonicity			GUARANTEED		
ADC internal clock[5]	f_{ADIC}	0.5	—	5	MHz
Conversion range	R_{AD}	V_{SSA}	—	V_{DDA}	V
Conversion time	t_{ADC}	—	6	—	t_{AIC} cycles[6]
Sample time	t_{ADS}	—	1	—	t_{AIC} cycles[6]
Input capacitance	C_{ADI}	—	5	—	pF[6]
Gain Error (transfer gain)[5]	E_{GAIN}	0.93	1.00	1.08	—

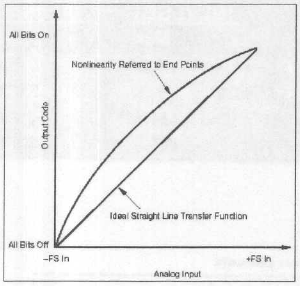
1. For optimum ADC performance, keep the minimum V_{ADCIN} value ≥ 25mV. Inputs less than 25mV may convert to a digital output code of 0.
2. V_{REF} must be equal to or less than V_{DDA} and must be greater than 2.7V. For optimal ADC performance, set V_{REF} to V_{DDA}-0.3V.
3. Measured in 10-90% range.
4. LSB = Least Significant Bit.
5. Guaranteed by characterization.

The data converter in the datasheet excerpt above is the from the ADC Characteristics table of the 56F807 device. This ADC is embedded in the controller. Note the test conditions stating that the ADC was tested at 4MHz, yet its maximum speed is 5MHz. How well does the part work at rated speed?

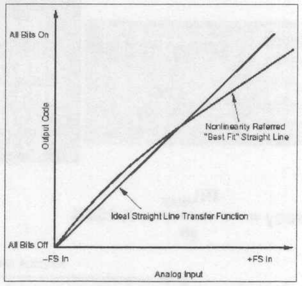
Take a look at note 1. The ADC input range is shown as 0-Vref, but you are advised to keep the input voltage above 25mV to achieve optimum performance. Note 3 is also interesting; as mentioned previously, linearity is a key measure of the converter accuracy, yet this device is production tested at 80% of the specified full scale range.

Probably the most disconcerting note is note 5 – Guaranteed by Characterization. What does that mean? That means the specification is not production tested.

Integral Nonlinearity (INL) Definition



Integral Nonlinearity referred to endpoints



Integral Nonlinearity referred to Best-Fit straight line

Burr-Brown Products from Texas Instruments

If you want your datasheet to look good...

Integral Non-Linearity refers to the deviation of each individual code from a line drawn from zero through full scale. The point used as zero occurs 1/2 LSB before the first code transition. The full-scale point is defined as level 1/2 LSB beyond the last code transition. The deviation is measured from the center of each particular code to the true straight line between these two points.

INL (integral nonlinearity) is defined as the integral of the DNL errors: good INL guarantees good DNL. Some datasheets only specify INL. INL error tells us how far away from the ideal transfer function value the measured converter result is. Unlike Gain and Offset Errors, INL and DNL errors can not be calibrated or corrected; they are inherent in the design and manufacture of the converter.

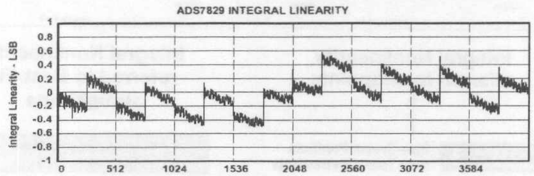
Some manufacturers use a Best Fit approach when specifying a devices INL, in some cases this can make the part appear better than it really is. Texas Instruments and Burr-Brwon Products from Texas Instruments takes the INL refered to the endpoints of the ideal transfer function which is generally concidered to be a more conservative measurement.

INL Comparison

Ideal Converter	Accuracy (%) Max
9 Bits	0.1953
10 Bits	0.0977
11 Bits	0.0488
12 Bits	0.0244

Device	INL (LSB)		Accuracy (%)
	Typ	Max	Max
ADS7829	±0.4	±1.25	0.0305
ADS7866	±1.0	±1.5	0.0366
56F807	±2.5	±4.0	0.0976
F2808	–	±1.5	0.0366

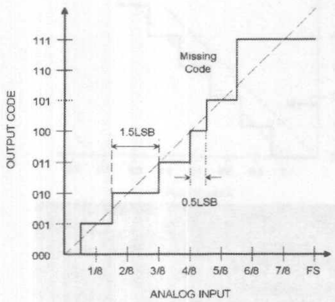
$$\text{Accuracy} = \frac{INL_{MAX}}{2^N} \times 100\%$$



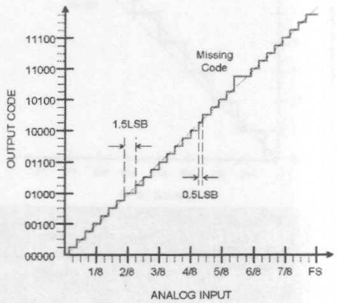
INL Comparison:

All four of the data converters listed in the table above are specified as 12-bit converters. The table to the left shows the accuracy of ideal 9-, 10-, 11- and 12-bit converters. Using the formula above, the calculated accuracy of the four converters in our example table can be easily derived. Comparing the actual accuracy, based on INL (max) of each converter listed to the ideal accuracy table, we can see that the ADS7829 and ADS7866 devices are 11.25 to 11.5-bits accurate. The Freescale device in our example is essentially accurate to 10-bits.

Differential Nonlinearity and NMC



3-bit resolution ADC



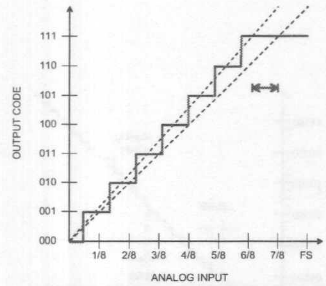
5-bit resolution ADC

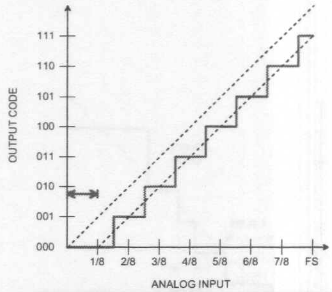
DNL (differential nonlinearity) specifies the deviation of any code in the transfer function from an ideal code width of 1 LSB. DNL is determined by subtracting the locations of successive code transition points after compensating for gain and offset errors. A positive DNL implies that a code is longer than the ideal code width. A negative DNL implies a code is shorter than the ideal width. DNL is measured in the increasing code direction of the transfer curve. The transition of code N is compared to that of Code N+1.

A DNL error of less than -1LSB implies that at least one code is missing, meaning that there is no analog voltage which will generate a particular code. Most manufacturers will include a “NO MISSING CODES” specification.

A modern SAR A/D converter uses an array of capacitors and a comparator to determine the value of each bit in the conversion result. Variations of the individual capacitors will produce periodic fluctuations in the DNL data. These variations can be seen in DNL vs Code plots of a datasheet.

Gain and Offset Comparison





DEVICE	Gain (%FSR)	
	Typ	Max
ADS7829	±0.007	±0.05
ADS7866	±0.007	±0.05
56F807	0	+8/-7
F2808	_	±1.464

DEVICE	Offset (mV)	
	Typ	Max
ADS7829	±0.18	±1.83
ADS7866	±0.05	±0.87
56F807	-25	+10/-90
F2808	_	±43.92*

***The F2808 has internal offset compensation which compensates for the offset. With compensation applied, the offset drops to ±4 LSB or ±2.92mV.**

Offset Error

The major carry transition should occur when the analog input is at zero volts. Offset error or zero error is defined as the deviation of the actual transition from the ideal transition point.

Gain Error

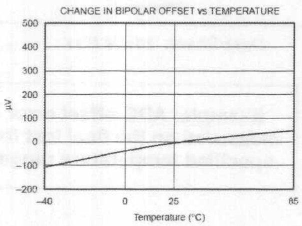
The first code transition should occur at an analog value 1/2 LSB above negative full scale. The last transition should occur at an analog value 1 1/2 LSB below the nominal full scale. Gain error is the deviation of the actual difference between first and last code transitions and the ideal difference between first and last code transitions.

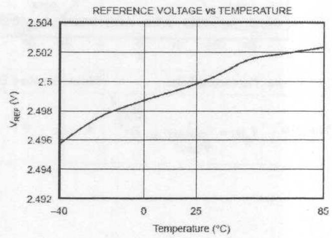
What Else Are You Missing?

Stand alone ADC datasheet has this data

Burr-Brown Products from Texas Instruments

Bipolar Offset Error	(V_{OS})			±0.5	±2	mV
Bipolar Offset Error Match		Channel 0/1, Same A/D		0.5	1	mV
Bipolar Offset Error Drift	(TCV_{OS})			0.4		ppm/°C
Gain Error[8]	(G_{ERR})			±0.05	±0.5	%
Gain Error Match				0.05	0.15	%
Gain Error Drift	(TCG_{ERR})			20		ppm/°C
Noise				60		µVrms
Power-Supply Rejection Ratio	(PSRR)	4.75V < AV_{DD} < 5.25V, with External Reference, at DC		–70		dB





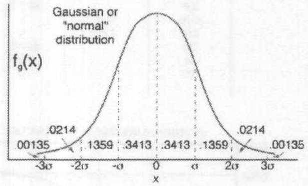
Is there anything else?

Stand alone converters have additional datasheet information which is typically not provided for an embedded converter. For example, the table above shows MIN and MAX (remember – these are production test windows) values for offset and gain over the full operating temperature range of the device.

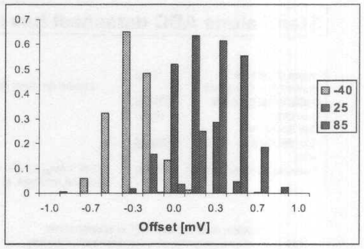
The curves above are based on characterization data. The endpoints are the production tested min and max values. The curves show a general tendency of the offset and gain error drift over temp. If the end system will only be operated in the reagion from 0 to 70 degrees C, the designer is provided with a good approximation of the drift the system might experience.

Production and Datasheet Target

Gaussian Distribution Function



Distribution	Functional Form	Mean	Standard Deviation
Gaussian	$f_g(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-a)^2}{2\sigma^2}}$	a	σ

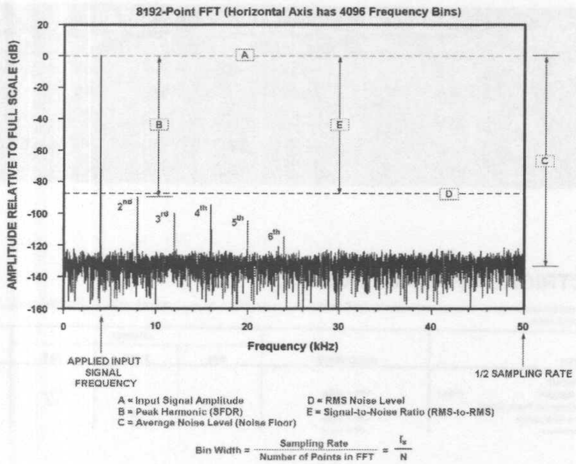


Data Sheet: ±1mV Max

Example: ADC offset error measured on the final test for specified temperature range

The Gaussian Distribution above represents the data which might be listed as typical offset errors for an embedded data converter. The actual production tests performed on stand alone converters set limits to ensure the overall distribution curve is centered between the MIN and MAX levels specified.

AC Parameter Basics



The figure above represents a typical FFT from a stand alone data converter such as the ADS7866. The labels in the plot indicate how the AC performance characteristics of a data converter are determined. The AC parameters (SFDR, SINAD, THD, etc.) for stand alone data converters are normally specified with the converter running at rated speed with a specific sine wave input frequency at a magnitude of FSR-0.2dB.

AC Parameters Comparison

Parameters		ADS7829 Typ	ADS7829 Max	ADS7866 Typ	ADS7866 Max	56F807 Typ	56F807 Max	F2808 Typ	F2808 MAX
THD	dB	-82	_	-83	-82	-64	-60	-79	_
SFDR	dB	85	_	85	_	70	65	83	_
SNR	dB	72.4	_	71	70	62.2	56.6	68	_
SINAD	dB	72	_	70.7	69.7	60	55	67.5	_
ENOB	bits	11.7	_	11.5	11.3	9.7	8.8	10.9	_

ELECTRICAL CHARACTERISTICS

Over recommended operating free-air temperature range at –40°C to 85°C, AV_{DD} = 5V, BV_{DD} = 3V, V_{REF} = internal +2.5V, f_{CLK} = 10MHz, and f_{SAMPLE} = 500 kSPS, unless otherwise noted.

PARAMETER	CONDITIONS	ADS8361 MIN	ADS8361 TYP[1]	ADS8361 MAX	UNITS
ANALOG INPUT					
Full-Scale Range[2] (FSR)	+IN – (–IN)			$\pm V_{REF}$	V
Operating Common-Mode Signal		2.2		2.8	V
Input Switch Resistance	$-IN = V_{REF}$		20		Ω
Input Capacitance	–IN = [illegible]		25		nF

THD is important for determining the accuracy of data converters since noise generated by the ADC, can not be removed from the conversion results. THD and other nonlinear error sources lower a devices SNR (with this specification, a higher value is desired).

The Effective Number of Bits (ENOB) gives a simple measure of a converters SNR, which can be compared with an ideal value to determine an ADC's dynamic accuracy. ENOB is derived from the theoretical definition of SNR.

For a sine wave input signal, the theoretical SNR is:

SNR = (6.02N + 1.76) dB 1
where N is the resolution
Solving for the resolution, (N):

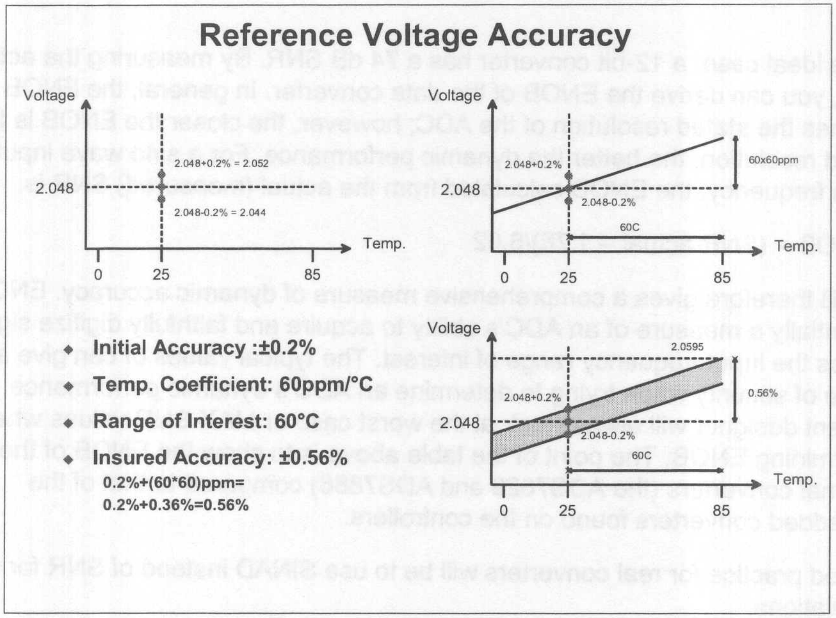
N = (SNR – 1.76)/6.02

In the ideal case, a 12-bit converter has a 74 dB SNR. By measuring the actual SNR, you can derive the ENOB of the data converter. In general, the ENOB never reaches the stated resolution of the ADC; however, the closer the ENOB is to the stated resolution, the better the dynamic performance. For a sine wave input at a given frequency, the ENOB calculated from the actual (measured) SNR is:

ENOB = (SNR actual – 1.76)/6.02

ENOB therefore gives a comprehensive measure of dynamic accuracy. ENOB is essentially a measure of an ADC's ability to acquire and faithfully digitize signals across the input frequency range of interest. The typical values of can give a false sense of security when trying to determine an ADC's dynamic performance. A prudent designer will always look at the worst case or MAX SNR values when determining ENOB. The point of the table above is to show the ENOB of the external converters (the ADS7829 and ADS7866) compared to that of the embedded converters found on the controllers.

A good practice for real converters will be to use SINAD instead of SNR for ENOB calculations.



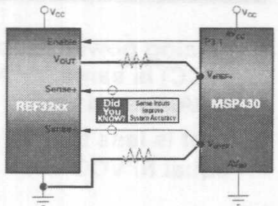
The initial accuracy of the REF30xx, REF31xx and REF32xx is ±0.2%. For reference voltage of 2.048V it is ensured that at 25°C the initial voltage will be between 2.044V and 2.052V.

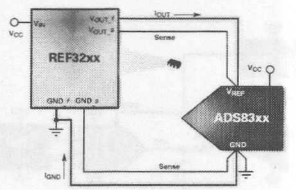
As the temperature is changing the output voltage will change too. In the data sheet temperature drift is specify for few different range. For example first is 0°C≤T_A≤ +125°C and the second one -40°C≤T_A≤ +125°C. For this application where operating point is 0°C≤T_A≤ +85°C we will use data for that range. In the case of REF30xx we will use 60ppm/°C. For the temperature range 25°C≤T_A≤ 85°C the output of the REF30xx will change less than ±3,600ppm or 0.36%.

Next step is to combine initial accuracy and temperature drift for the temperature in the range 0°C≤T_A≤ 85°C. The REF30xx's total error will be ±0.2% ±0.36% or ±0.56%.

Reference Voltage: Internal vs. External

Device	Initial Accuracy (%)	Tmp.Coef. (ppm/°C)		Total Accuracy (%)	
	Max	Typ	Max	Typ	Max
MSP430F167	±4	–	±100*	–	±4.60
56F807	–	–	–	–	–
F2808	–	±50	–	?	–
ADS7829	–	–	–	–	–
ADS7866	–	–	–	–	–
ADS1203	±2	±20	–	±2.12	–
ADS8361	±1	±20	–	±1.12	–
REF29xx	±2	±35	±100	±2.21	±2.60
REF30xx	±0.2	±20	±50	±0.32	±0.50
REF31xx	±0.2	±5	±15	±0.23	±0.29
REF32xx	±0.2	±4	±7	±0.22	±0.24

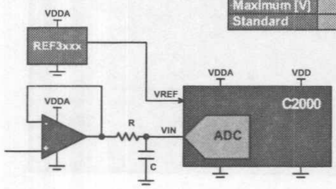




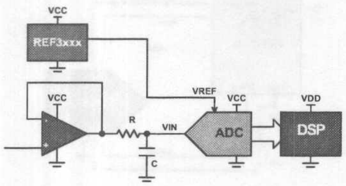
The table above compares the initial and total accuracy of typical voltage references found onboard the standalone data converters as well as those found on host processors. We can further compare these values to external devices which are designed for one specific purpose – to provide accurate, stable reference voltages. Recalling the ruler example to show accuracy, we can relate the accuracy of data conversion results directly to the accuracy of the applied reference voltage.

Power Supply Guideline

Type	CMOS/TTL		LVTTL			2.5V	
Range	Commercial	Extended	Narrow	Normal	Extended	Normal	Extended
Nominal [V]	5	5	3.3	3.3	3	2.5	2.5
Minimum [V]	4.75	4.5	3.15	3	2.7	2.3	1.8
Maximum [V]	5.25	5.5	3.45	3.6	3.6	2.7	2.7
Standard	EIA/JESD 12-6		EIA/JESD 8A			EIA/JESD 8-5	



REF02								5
REF1004	1.235		2.5					
REF29xx	1.25	2.048	2.5	3.0	3.3	3.6	4.096	
REF1112	1.25							
REF30xx	1.25	2.048	2.5	3.0	3.3	3.6	4.096	
REF31xx	1.25	2.048	2.5	3.0	3.3	3.6	4.096	
REF32xx	1.25	2.048	2.5	3.0	3.3	3.6	4.096	



- Analog power supply (VCC) is same for ADC, OpAmp and REF.
- Vref is less than or equal to VCC

When choosing an external reference, it is important to remember to tie all the analog supply voltages together. For example, when using an external data converter that runs from a nominal 5V analog supply, best performance will be obtained when the associated drive amplifier and the reference itself all use the same voltage source. This is also the case when using the embedded ADC found in controllers such as those in the C2000 family of DSP's.

Part Number	Power Supply [V]			External Reference	Analog Input [V]	
	Min	Typ	Max		Min	Max
TMS320LF2407A	3	3.3	3.6	REF3030	0	3
TMS320LF2406A	3	3.3	3.6	REF3030	0	3
TMS320LF2403A	3	3.3	3.6	REF3030	0	3
TMS320LF2402A	3	3.3	3.6	REF3030	0	3
TMS320LF2401A	3	3.3	3.6	NA	0	V_{DDA}
TMS320LC2406A	3	3.3	3.6	REF3030	0	3
TMS320LC2404A	3	3.3	3.6	REF3030	0	3
TMS320LC2403A	3	3.3	3.6	REF3030	0	3
TMS320LC2402A	3	3.3	3.6	REF3030	0	3
TMS320LC2401A	3	3.3	3.6	NA	0	V_{DDA}
TMS320F243	4.5	5	5.5	REF3040	0	4.096
TMS320F241	4.5	5	5.5	REF3040	0	4.096
TMS320F240	4.5	5	5.5	REF3040	0	4.096
TMS320C242	4.5	5	5.5	REF3040	0	4.096
TMS320R2812	3.14	3.3	3.47	NA	0	3
TMS320R2811	3.14	3.3	3.47	NA	0	3
TMS320F2812	3.14	3.3	3.47	NA	0	3
TMS320F2811	3.14	3.3	3.47	NA	0	3
TMS320F2810	3.14	3.3	3.47	NA	0	3
TMS320F2808	3.14	3.3	3.47	REF3220	0	3
TMS320F2806	3.14	3.3	3.47	REF3220	0	3
TMS320F2801	3.14	3.3	3.47	REF3220	0	3
TMS320C2812	3.14	3.3	3.47	NA	0	3
TMS320C2811	3.14	3.3	3.47	NA	0	3
TMS320C2810	3.14	3.3	3.47	NA	0	3

The table above provides a convenient list of the TMS320x2xxx devices, the typical supply voltage applied to the embedded converter found on those devices, as well as a recommended external reference that provides a full scale input range for the applied analog signal.

High Performance Analog Outline

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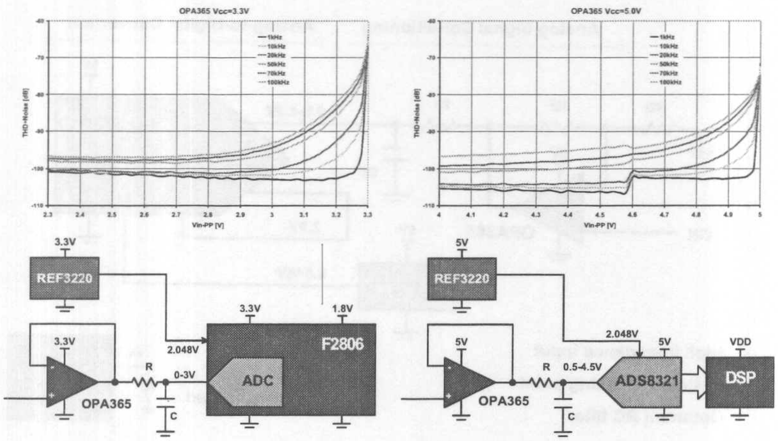
  - Accuracy vs. Resolution
  - Datasheet and Reference Voltage Concerns
- **Part II: Data Converter Drive Concerns**
  - Low Voltage Drive to Embedded ADC
  - High Voltage (±10V) Interface to ADC and DAC
- **Part III: Analog Front End for Motor Control**
  - Interfacing Sine/Cosine Encoder
  - Complete High Accuracy DMC Solution
- **Part IV: Current Measurement Options**
  - Delta-Sigma Modulator Solutions
  - Current Shunt Monitors
  - Isolation Solutions
- **Part V: Tools for High Performance Analog**

Part II: Data Converter Drive Concerns

The analog input to a motor control system can be more complex than the actual drive algorithms – especially if you're a digital designer and need to close the analog loop. The subject material in this section will briefly discuss several ways to interface analog signals to the DMC system (i.e. ±10V command inputs).

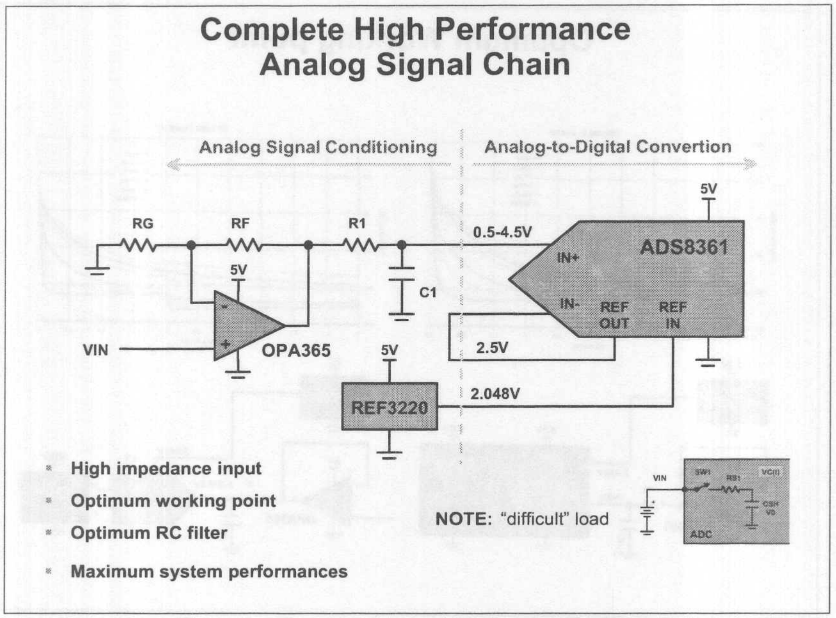
We will explore ways to talk directly with the ADC found internal to TMS320C28xx devices as well as a few select external data converters. A introduction to digital to analog conversion (DAC) will also be presented.

Optimum Working point



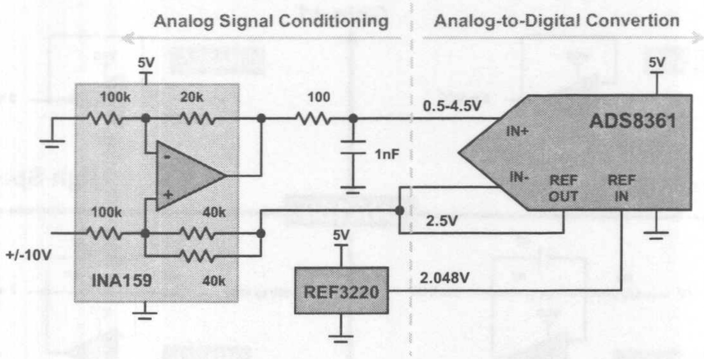
Working with low voltage and/or single supply op amps can be tricky business. The schematic diagrams show some typical drive configurations to both the 2000 series DSP and a stand alone data converter. Op amps such as the OPA365 do not exhibit the cross over distortion problems found in normal rail to rail op amps, the THD performance of this device is a function of input frequency and applied voltage. For input frequencies below 100K, the OPA365 provides greater than 93dB THD. The schematic above on the left provides one example of how to drive a 0-3V signal to the internal ADC of a C2000 controller with a 3.3V supply. Full scale input to the converter however is limited by the applied reference voltage (2.048V).

If working with an external data converter such as the ADS8321 with an applied Vcc of 5V, the full scale input range increases to 4Vpp with 97dB THD at 100kHz.



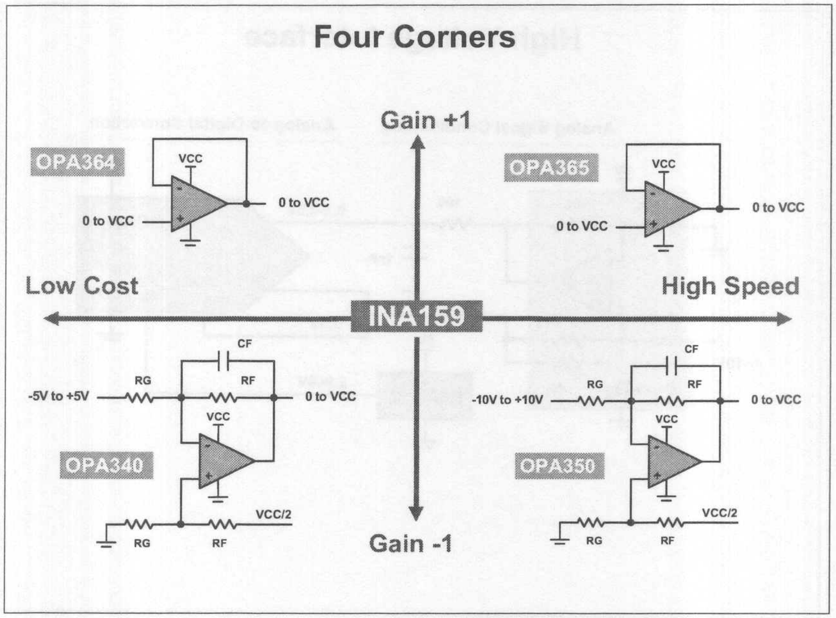
The diagram above shows how to use the OPA365 operating at 5V to provide a 4Vpp signal to the ADS8361 using a 2.048V (REF3220) external reference for the conversion reference, and the ADS8361's internal reference for bias.

High Voltage Interface



The difference amplifier is the foundation of many commonly used circuits. The INA159 provides this circuit function without using an expensive external precision resistor network. The INA159 is available in an MSOP-8 surface-mount package and is specified for operation over the extended industrial temperature range, −40°C to +125°C.

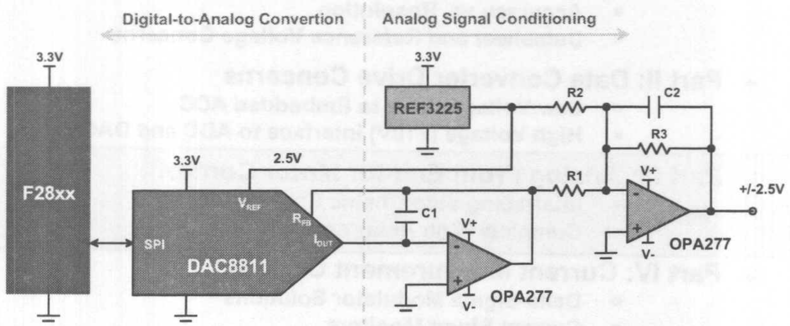
The circuit above shows a simple method of applying ±10V (20Vpp) signals to a data converter using only 5V supplies. For direct application to the data converters found in the C2800 DSP family, a 3.3V supply can be used with the INA159 to provide scaled results similar to that of the ADS8361 example shown above.



The devices shown in the four corners of this slide provide excellent single supply performance for a variety of applications. For simple buffers, the OPA364 and OPA365 provide excellent THD performance with none of the cross over distortion problems associated with rail to rail op amps. The OPA340 and OPA350 provide excellent performance when configured as inverting amplifiers.

The INA159 is a high slew rate, G = 1/5 difference amplifier consisting of a precision op amp with a precision resistor network. The gain of 1/5 makes the INA159 useful to couple ±10V signals to single-supply analog-to-digital converters (ADCs), particularly those operating on a single +5V supply.

Analog Output and Monitoring



Multiplying DACs

Burr-Brown Products from Texas Instruments provide a large variety of multiplying DAC's which can be used as DMC output/system monitor devices. The DAC8811 shown above is a 16-bit device capable of providing ±10V outputs. The schematic as shown above, will provide ±2.5V outputs. The DAC8811 is compatible with the SPI interface of the C2000 family of DSP's.

The selection of the op-amp on the out put of this device depends primarily on speed and linearity. The OPA277 is chosen here for precision. For higher speed applications, the OPA277 can be replaced with the OPA227.

Texas Instruments has developed a special tool for these current output DAC's called "I to V Pro". The tools is a free download from the TI Analog website (analog.ti.com), is relatively simple to use and provides a list of operational amplifiers that suit particular design needs such as output voltage swing, single, dual or quad multiplying options and also provides a schematic and suggested component values.

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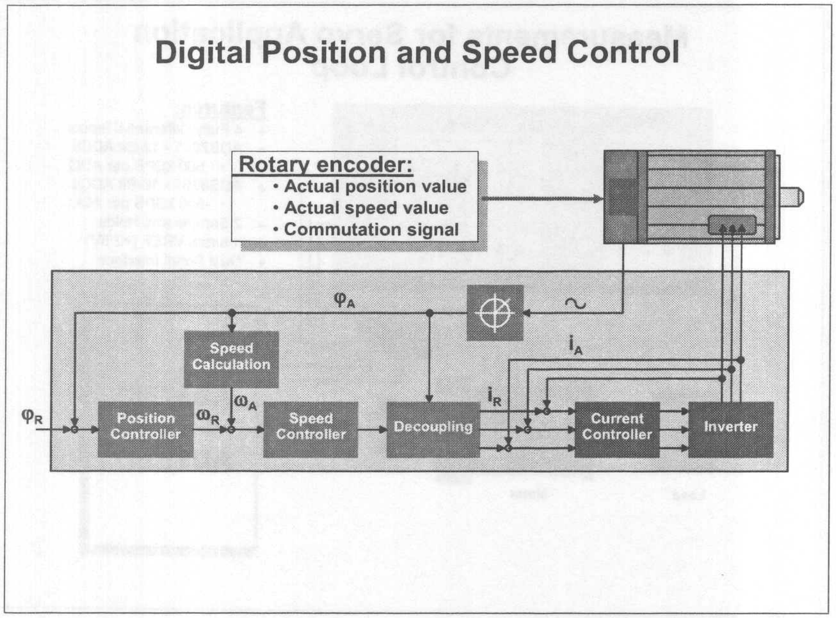
Part III: Analog Front End for Motor Control

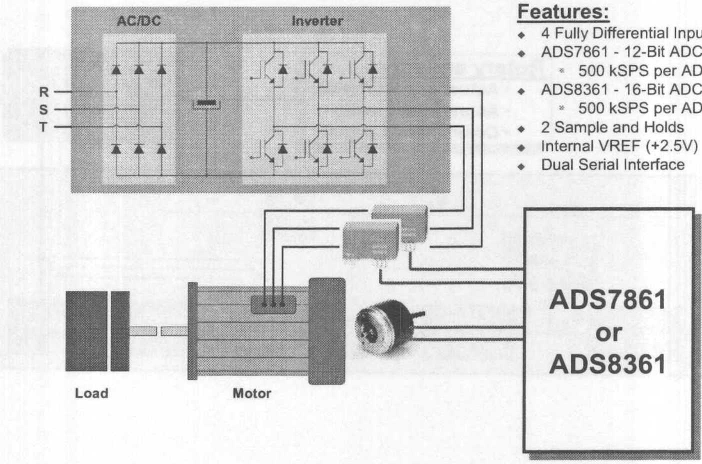
This section of our presentation deals with several methods of interfacing a sinusoidal encoder (motor and/or load coupled) as well as current monitoring solutions for digital motor controllers. We'll begin by looking at the analog interface to the embedded converters found on the C2000 series DSP's.

The ADS7869, which is a complete motor-control front-end that includes three analog-to-digital converters (ADCs) with a total of seven sample-and-hold capacitors and 12 fully differential input channels will be discussed. In addition, we look at several methods of using other stand alone converters such as the ADS8361 and ADS8364 to performa the same tasks.



Controlling systems for servo drives require measuring systems that provide feedback for the position and speed controllers and for electronic commutation. Encoders have influence on positioning accuracy, speed stability, drive bandwidth (command-signal response and disturbance rejection), power loss, size, quietness, etc.

Measurements for Service Application Control Loop

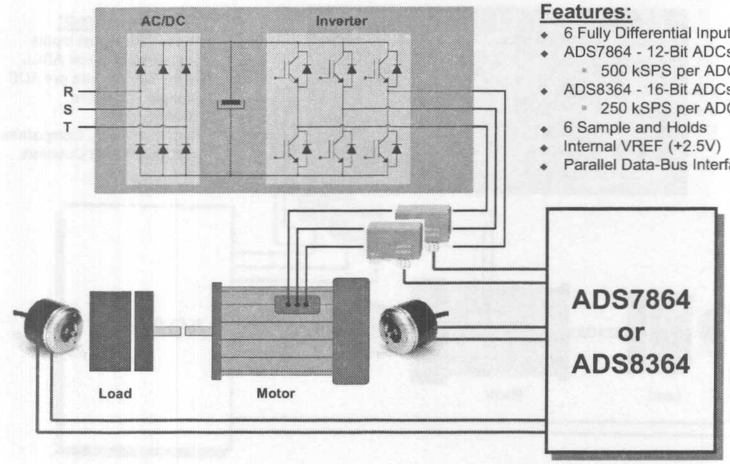


Features:

- 4 Fully Differential Inputs
- ADS7861 - 12-Bit ADCs
  - 500 kSPS per ADC
- ADS8361 - 16-Bit ADCs
  - 500 kSPS per ADC
- 2 Sample and Holds
- Internal VREF (+2.5V)
- Dual Serial Interface

Our block diagram above shows the flexibility of two data converters specially designed for motor control applications. The ADS7861 and ADS8361 are pin compatible 12- and 16-bit converters which feature 2 pairs of simultaneously sampled signals. The both offer fully differential inputs and a simple SPI interface. Two serial output pins can provide conversion rates up to 500kSPS per channel (1MSPS effective). Our example here shows how a single device can be used to simultaneously measure two phase currents and the position signals from a sinusoidal encoder.

Measurements for Servo Application Control Loop

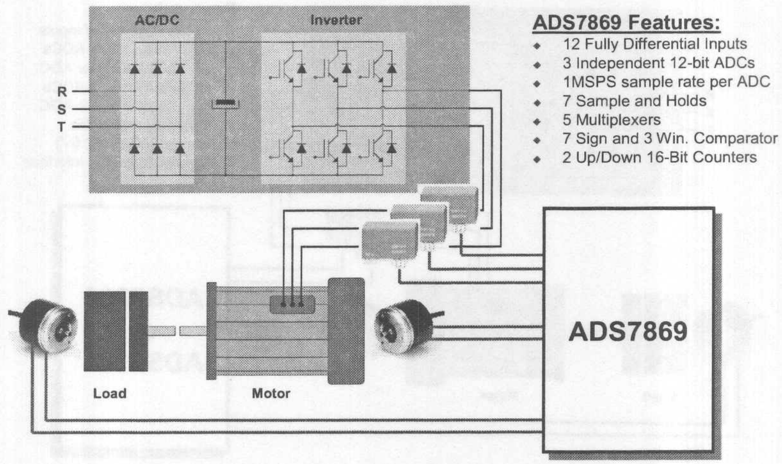


Features:
- 6 Fully Differential Inputs
- ADS7864 - 12-Bit ADCs
  - 500 kSPS per ADC
- ADS8364 - 16-Bit ADCs
  - 250 kSPS per ADC
- 6 Sample and Holds
- Internal VREF (+2.5V)
- Parallel Data-Bus Interface

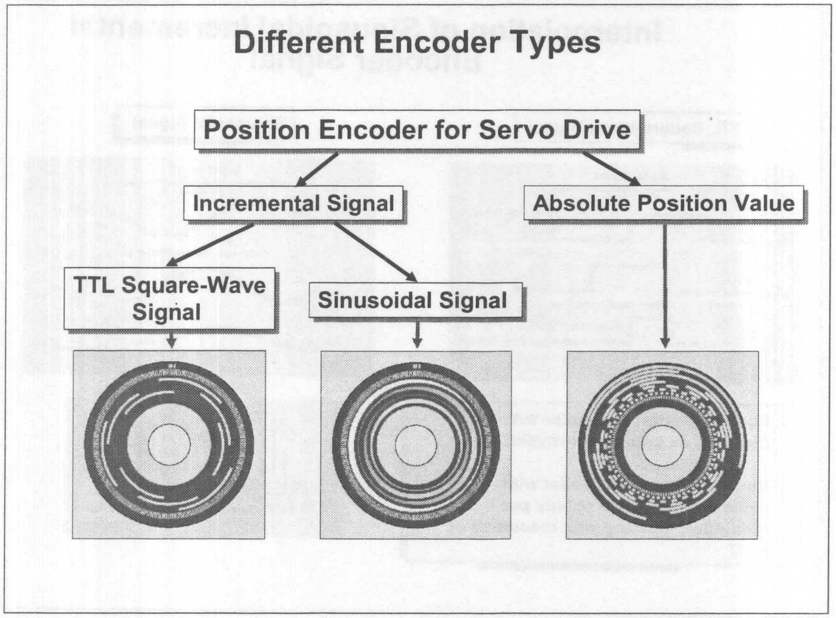
This block diagram above shows the flexibility of two additional data converters specially designed for motor control applications. The ADS7864 and ADS8364 are 12- and 16-bit converters which feature 6 fully differential, simultaneously sampled input channels.

The example above demonstrates how two phase currents and two sinusoidal encoders (one on the motor, one on the load) can be applied to these converters.

Measurements for Servo Application Control Loop



The ADS7869 is a unique member of the motor control related data converter products from Texas Instruments. This block diagram above shows the ability of the ADS7869 to simultaneously sample up to seven input channels. The samples are then fed to three independent on chip data converters that operate at a maximum speed of 1MSPS!



Sinusoidal Encoders

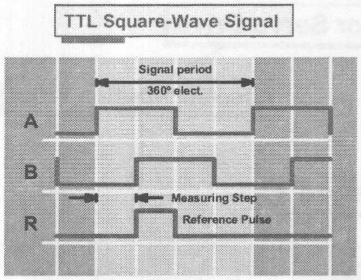
The last three block diagrams all included the use of sinusoidal encoders for collection of rotor position information. To ensure smooth drive performance, an encoder must provide a large number of measuring steps per revolution. At low speeds, the position error of the encoder within one signal period affects speed stability.

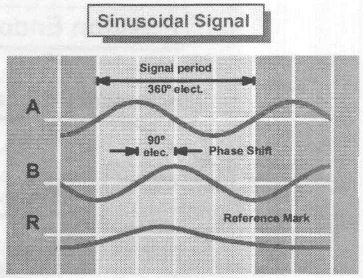
For standard drives, manufacturers primarily use encoders with TTL-comparative output signals as well as additional commutation signals for permanent-magnet dc drives. 60,000 measuring steps per revolution are sufficient.

For digital speed control on machines with high dynamic requirements, a large number of measuring steps are required (usually > 500,000 per revolution). Encoder sinusoidal incremental signals with signal levels of 1 V_{P-P} can be highly interpolated in the subsequent electronics.

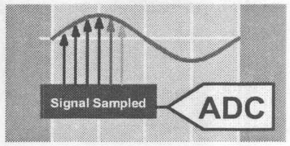
For example, a rotary encoder with 2048 signals periods per revolution and a 1024-fold subdivision in the subsequent electronics produces approx. 2 million measuring steps per revolution. This corresponds to a resolution of 21-bits. Even at shaft speeds of 12,000 rpm, the signal arrives at the input circuit of the controlling system with a frequency of only approx. 400 kHz

Interpolation of Sinusoidal Incremental Encoder Signal





- **Resolution of the encoder with TTL Signal is 4x counts per revolution**
- **Resolution of the encoder with sinusoidal signal is counts per revolution multiply with resolution of ADC**

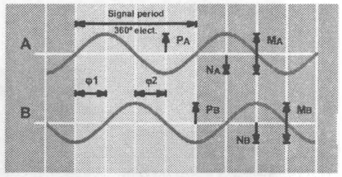


Quadrature encoders with 1024 lines can provide a maximum of 4096 (12-bit) position information. Using a sinusoidal encoder with a simultaneous sampling 12-bit ADC such as the device found internal to the F28xx, the sampling rate of the converter can increase the resolution by a factor 2^{12}.

Interfacing Incremental Encoder Sinusoidal Signals

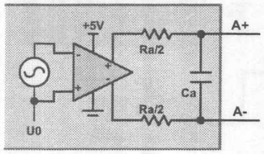
Sinusoidal Voltage Signals

Signal Amplitude M: 0.6 to 1.2V
Asymmetry |P-N|/2M : ≤ 0.065
Amplitude Ratio M_A/M_B: 0.8 to 1.25
Phase Angle|φ1-φ2|/2: 90° ±10° elec.

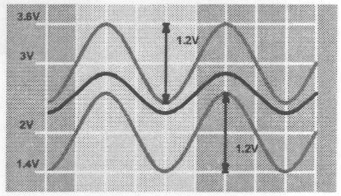


Offset voltage can be in the range from 2 to 3V
Amplitude of the output voltage is from 0.6 to 1.2V_{PP}
Output signal can be anywhere in the range from 1.4 to 3.6V

Encoder

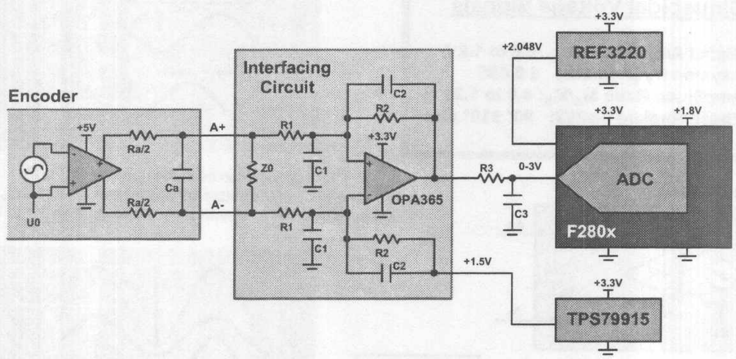


R_a <100Ω
C_a <50pF
I_0 <1mA
U_0 =2.5V±0.5V

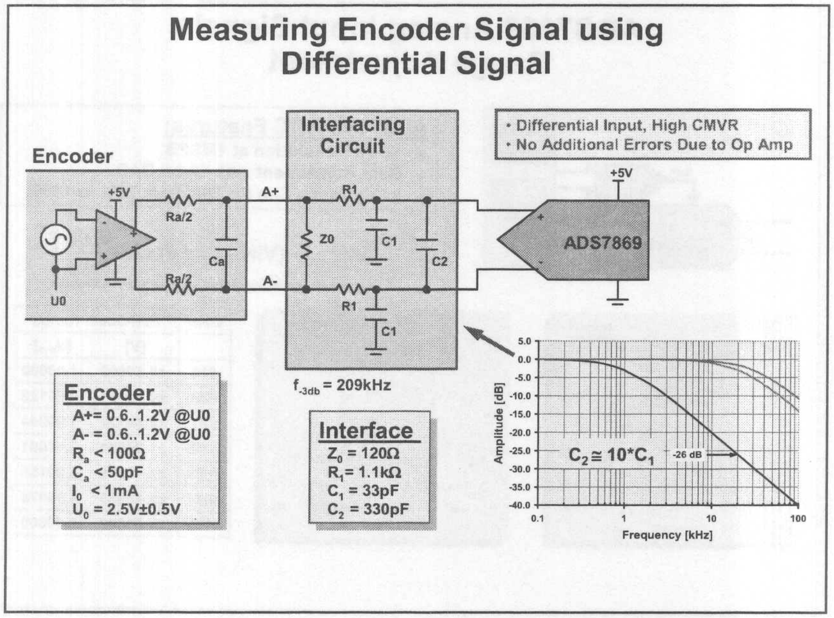


The output voltage swing and offset of a sinusoidal encoder will determine what steps are necessary to interface the device to converters such as the ADC found on the F28xx series of controllers, or external devices such as the ADS7869 or ADS7861. The ADC must be able to handle the encoder signals directly, or supporting circuitry must be used to apply gain and or level shift the signals.

Measuring Encoder Signal using Single Ended Signal

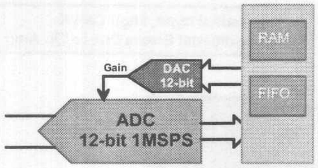


The application circuit above shows one potential method of connecting an encoder such as the ROD-486 from Heidenhaim to the internal converter found on the F280x series DSP. The interface circuit consists of the OPA365 and a 1.5V regulator (theTPS79915) which is used to offset the input signal to the midpoint of the analog input span of the data converter. Gain must be adjusted by selecting appropriate resistor values for R1 and R2



This application circuit shows a method of connecting the same encoder discussed on the previous slide to the ADS7869. The interface circuit consists of a simple RC filter circuit. Now that we have the interface, we'll take a look at some unique features of the ADS7869 to handle offset and gain issues of the encoder signals.

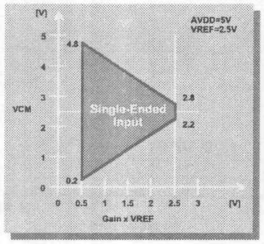
ADS7869 Analog Input Signals Range Adjustment

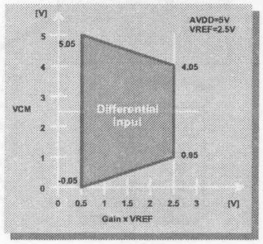


ADS7869 ADC Features:

- 12-bit Resolution at 1MSPS
- Gain Adjustment with 12-bit DAC
- Input Range Can Be Selected: 20% to 100%

$$(VIN+) - (VIN-) = \pm Vref \times \frac{Gain}{4095}$$

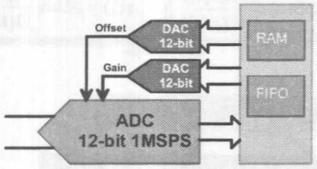




Gain	Full-Scale Range	
	[V]	$[V_{P-P}]$
819	±0.50000	1.00000
820	±0.50061	1.00122
821	±0.50122	1.00244
2048	±1.25031	2.50061
4093	±2.49878	4.99756
4094	±2.49939	4.99878
4095	±2.50000	5.00000

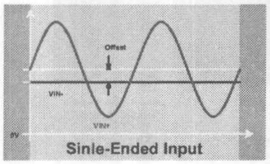
One of the unique features of the ADS7869 is the inclusion of a 12-bit DAC that can be used to adjust the gain of the internal ADC's. The device also includes 40 words of internal RAM to store gain, offset and other values.

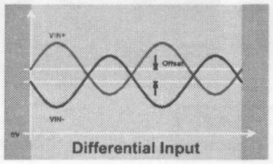
ADS7869 Analog Input Signals Offset Adjustment



ADS7869 ADC Features:
- Offset Adjustment with 12-bit DAC
- 10-bit Offset Registers are Available
- Offset Can Be Selected from 0 to ±12.5% of the Input Range

$$Input\_Offset = FSR \times \frac{Offset}{4096}$$





Offset Register [Dec]	[Hex]	Offset
511	1FF	12.48%
510	1FE	12.45%
...	...	...
1	001	0.02%
0	000	0.00%
-1	3FF	-0.02%
...	...	...
-510	202	-12.45%
-511	201	-12.48%

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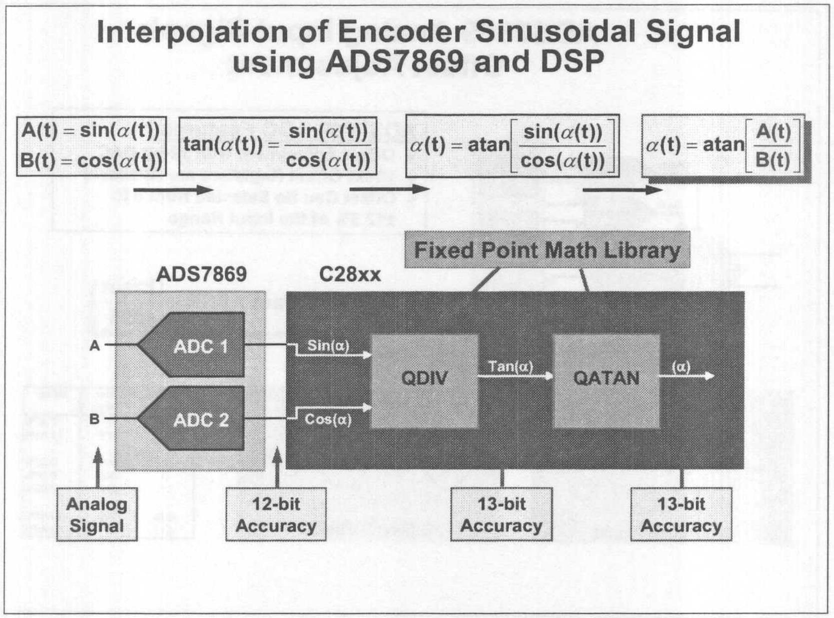

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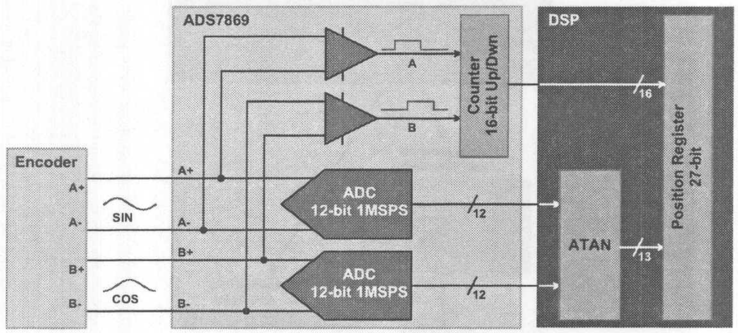
Interfacing DSP and Encoder Using ADS7869



Internal components of the ADS7869 make possible and easy 27-bit position information in real-time.

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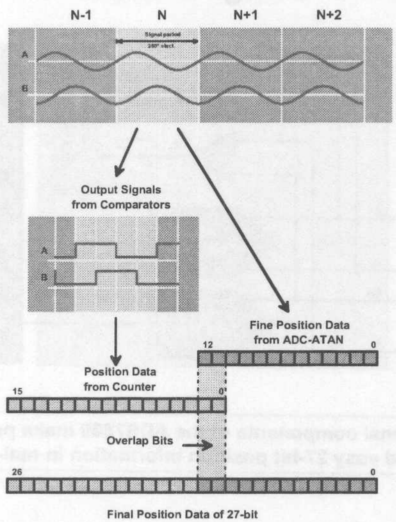
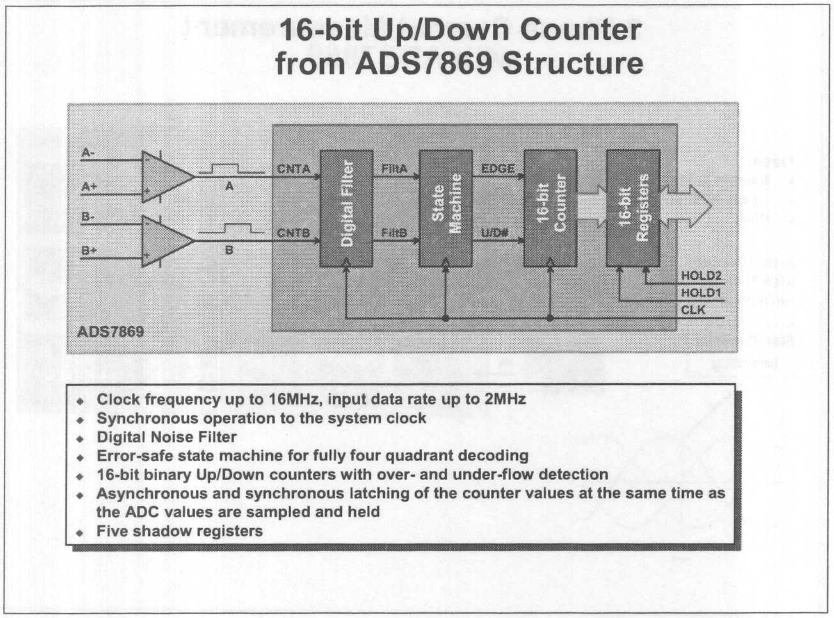
Creating Position Data from ADS7869



- Two encoder output differential signals are directly interface to the two differential inputs on ADS7869.
- Two 12-bit ADCs on the ADS7869 sample and convert SIN and COS signals simultaneously.
- Results from the conversion are passed through ATAN calculation block which provide fine position data with 13-bit accuracy.
- Same input signals into the ADS7869 are passed through comparators that make square-wave signals.
- After processing square-wave signals by counter, the 16-bit result is obtained.
- Final position data of 27-bits is obtained combining results from the ADC and counter.



Clock frequency up to 16MHz, input data rate up to 2MHz

Synchronous operation to the system clock

Digital Noise Filter

Error-safe state machine for fully four quadrant decoding

16-bit binary Up/Down counters with over- and under-flow detection

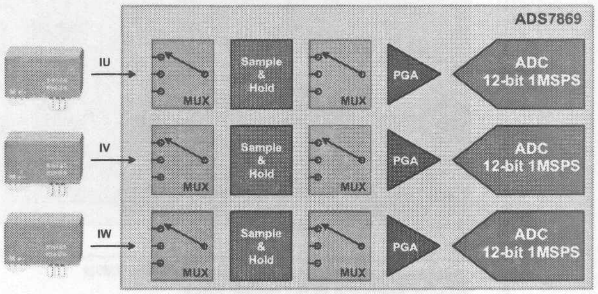
Asynchronous and synchronous latching of the counter values at the same time as the ADC values are sampled and held

Five shadow registers

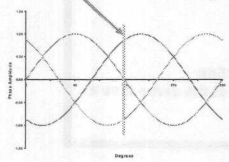
3 Phase Current Measurement with ADS7869

Three:
- Sample & Hold
- 12-bit ADC 1MSPS
- PGA

iu(t)=IU sin(ωt)
iv(t)=IV sin(ωt+120°)
iw(t)=IW sin(ωt-120°)



Simultaneous Sampling



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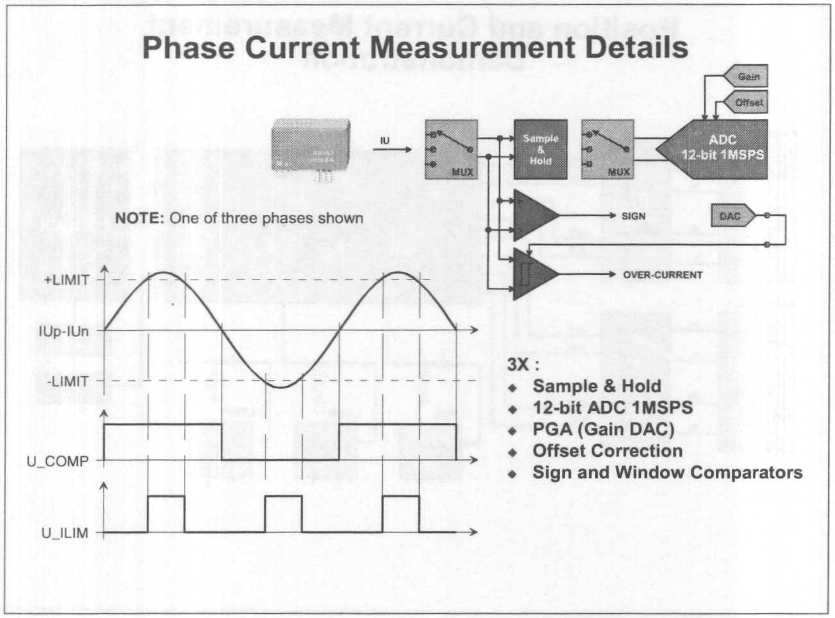


Three Simultaneous Sampling Inputs

No time difference error in sampling of signals

Three Differential Inputs

High CMRR for noisy environment

Three PGA Simultaneously Scaling Inputs

Same HW for different power range

Three 12-bits 1MSPS ADCs

Low delay in control algorithm

Three Sign Comparators

SW Lockout time compensation

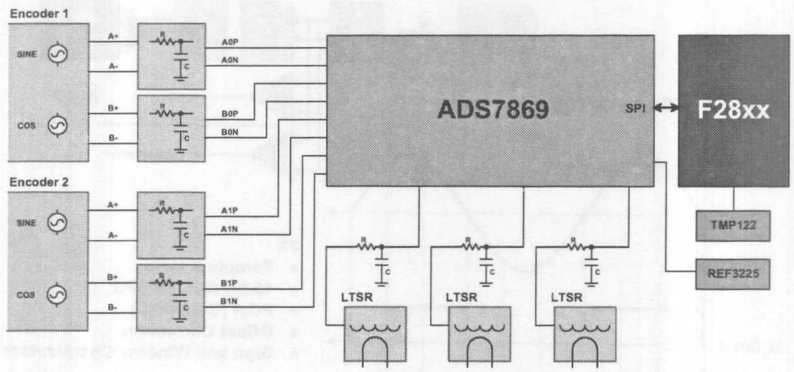
One 8-bit DAC for Set-up of Current Limit

Dynamic control of motor acceleration

Three Programmable Window Comparators

Separate control of motor phases over-current

Position and Current Measurement Demonstration



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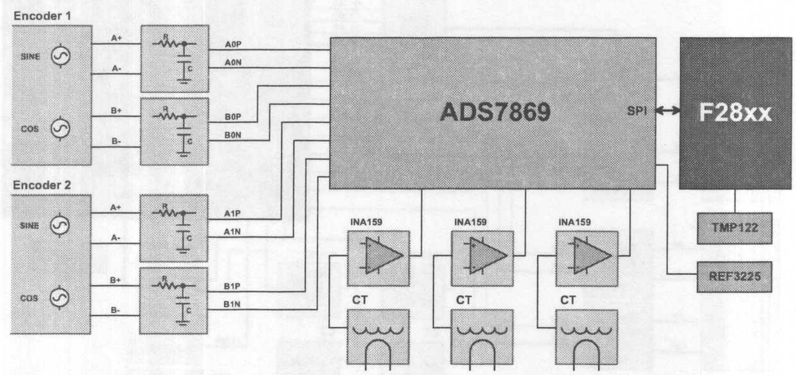
Current Transformer Measurements



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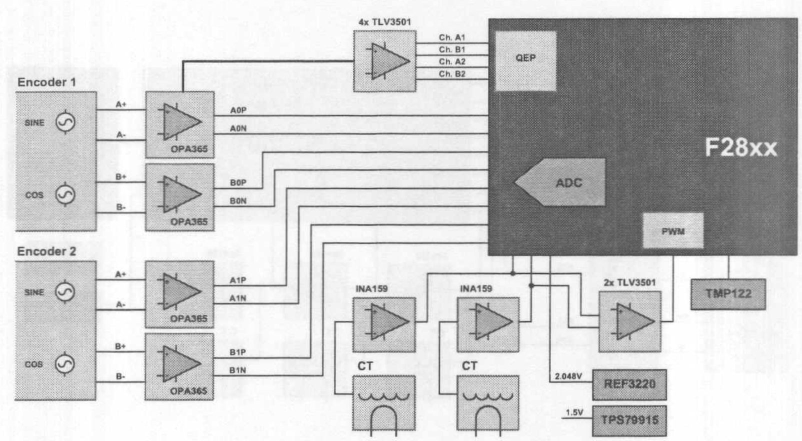
Measurements using the Embedded ADC



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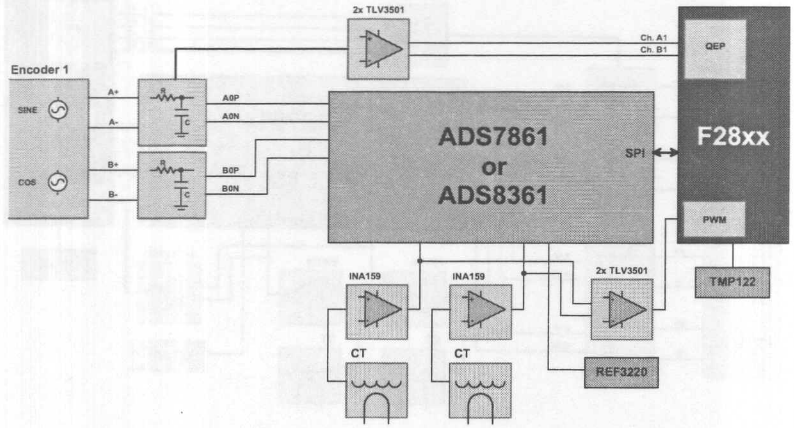
External ADC with Four Channels



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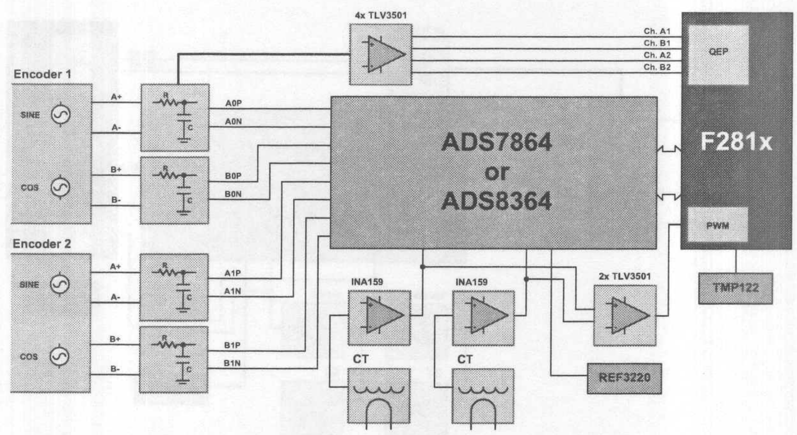
External ADC with Six Channels



Space available for note taking:

High Performance Analog Outline

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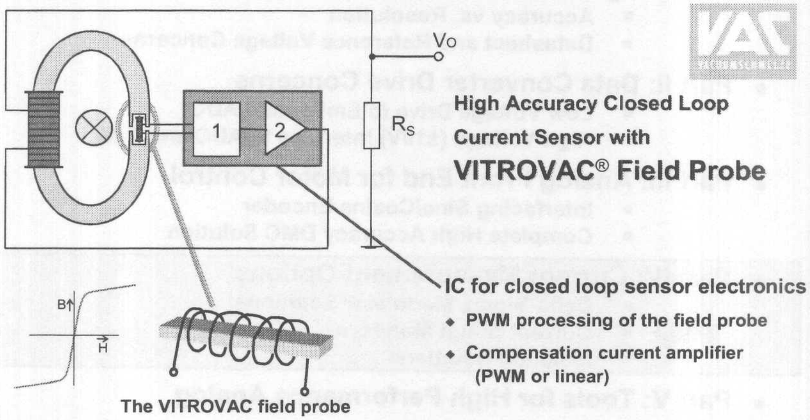
  - **Interfacing Sine/Cosine Encoder**
  - **Complete High Accuracy DMC Solution**
- **Part IV: Current Measurement Options**
  - **Delta-Sigma Modulator Solutions**
  - **Current Shunt Monitors**
  - **Isolation Solutions**
- **Part V: Tools for High Performance Analog**

Part IV: Current Measurement Options

This section of today's presentation will cover several methods for monitoring currents in motor control systems. Our focus will be closed loop sensors, open loop sensors and shunt resistors. We will introduce several new Delta-Sigma modulators designed specifically for current shunt monitoring and provide details about new high-speed 4KV Isolation products from Texas Instruments.

Current Sensors
Principle of Operation



Current measurement with combination of VAC sensor and DRV401:

Measurement of DC and AC current up to a bandwidth of 200Khz

Inherent galvanic isolation

Nominal current ranges starting at ±10A up to several hundred amps.

Improved accuracy and especially improved drift of offset and gain vs. other manufactures

Example, 25A module:

Accuracy	0.5% max
Drift error over -40 to +85C	0.2% max
Offset error	0.1%FS max
Offset Error drift over -40 to +85C	0.05%FS max

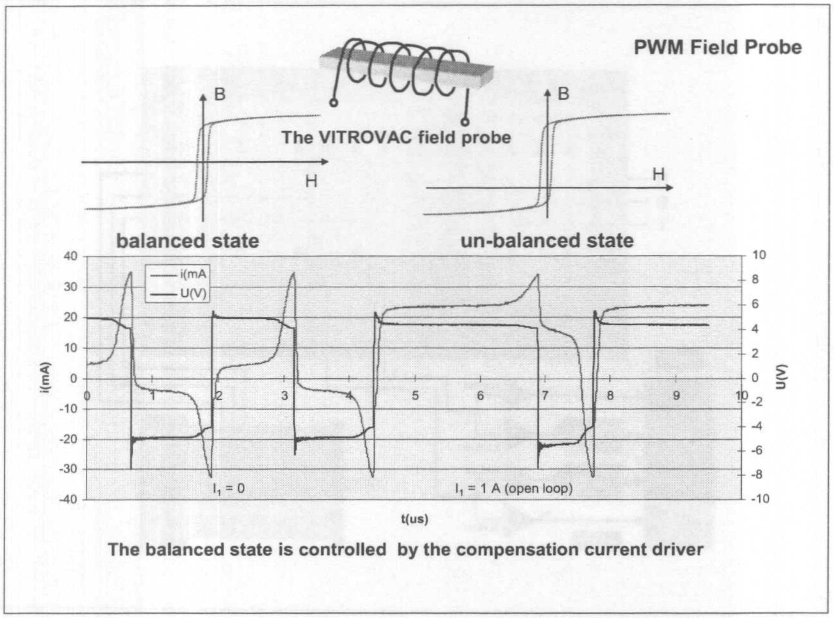
Cooperation with VAC offers 3 options

Pin compatible versions to industrial standards, complete module

Improved Versions, complete module

Separate Sensor and signal conditioning

Digital Motor Control



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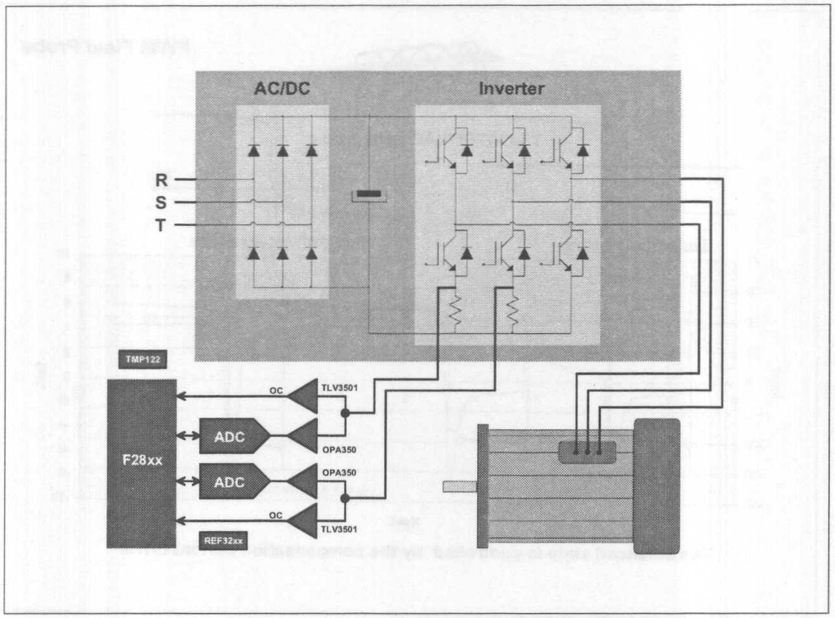

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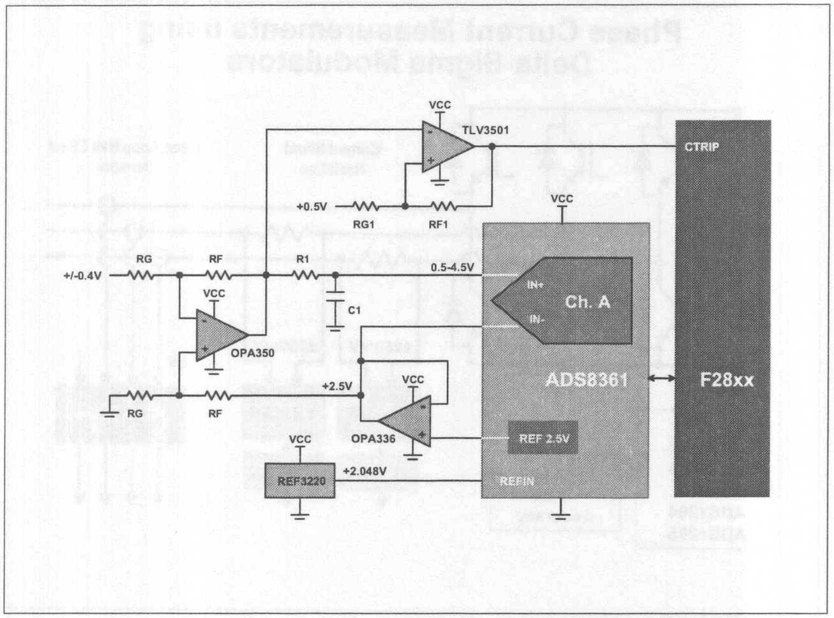

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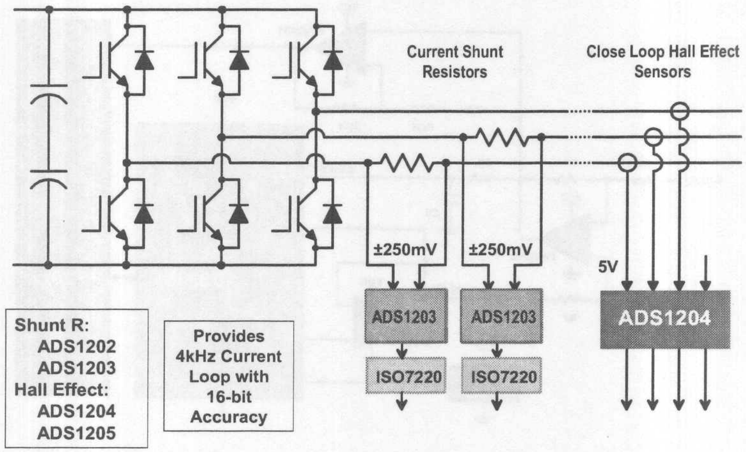
Phase Current Measurements using Delta-Sigma Modulators



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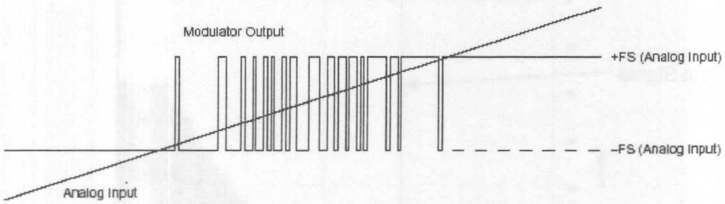
Delta-Sigma Modulator Output



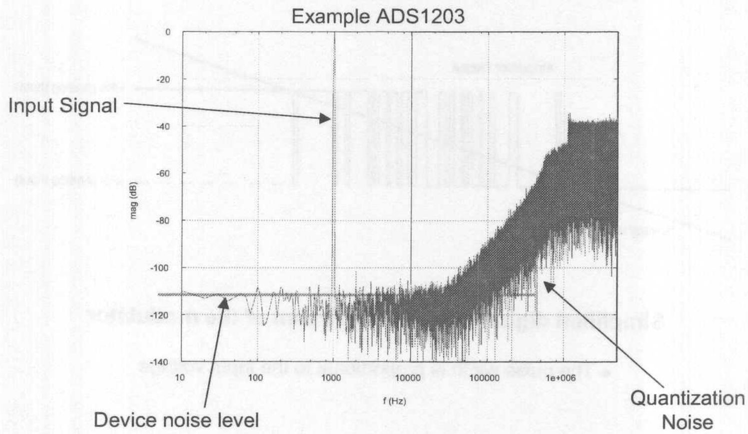
Simplified digital output data stream of the modulator

- The pulse width is proportional to the input voltage

Simplified output of a Delta-Sigma Modulator:

The digital output of a Delta-Sigma Modulator is essentially a PWM data stream. The data stream is related to the analog input to the device – full scale negative provides all zeros while full scale positive input provides all ones. Mid Range input provides a 50/50 duty cycle output. This data stream needs to be fed into a series of filters that integrates and then decimates the information to provide a meaningful output to the control system.

FFT of Delta-Sigma Modulator Output



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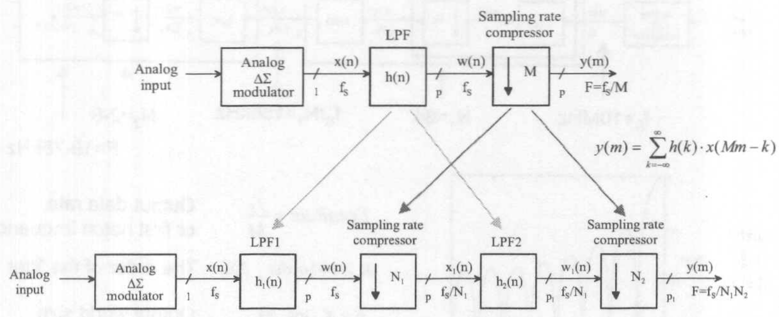
Decimation for Delta-Sigma Modulator

Basic block diagram of decimation for ΔΣ converter



Two-stage network for decimation by a factor of $N_1 \times N_2$

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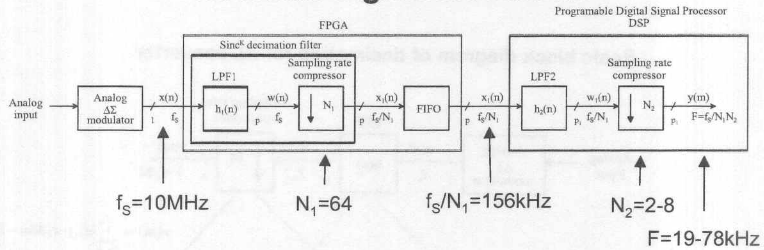
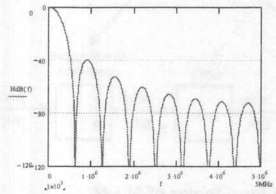
Decimation Filter Implementation for Delta-Sigma Modulator



Sinc^3
K=3
M=16



$$DataRate = \frac{f_S}{M}$$ Output data rate, or first notch frequency

$$K \geq 1 + (order\_\Delta\Sigma)$$ The order of the filter

$$p = K \cdot \log_2 M$$ Output world size

With Decimation Ratio = 64; Data Rate = 156.2kHz; Output Word = 18-bit; f-3dB = 40.9kHz

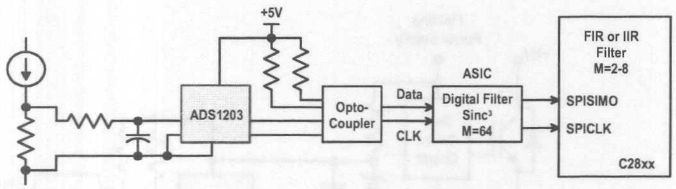
Data rate is M times smaller than sampling frequency, 10MHZ.

Sinc^2 filter –3dB response point is 0.318 times the data rate.

Sinc^3 filter –3dB response point is 0.262 times the data rate.

This point is very dependant of the filter order and les of the decimation ratio.

Current Measurement using Shunt Resistor



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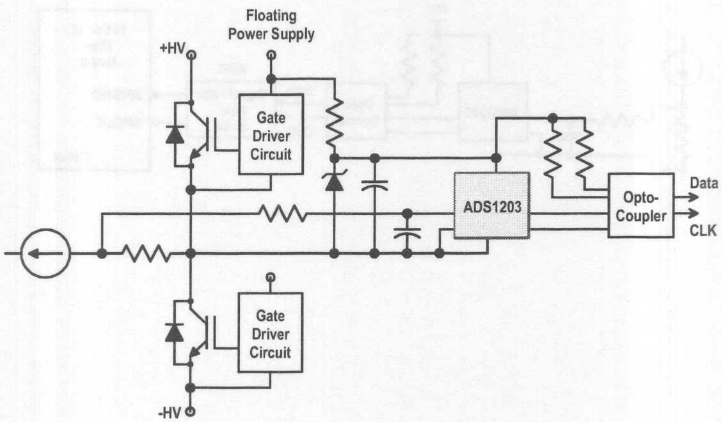
Current Measurement using Shunt Resistor



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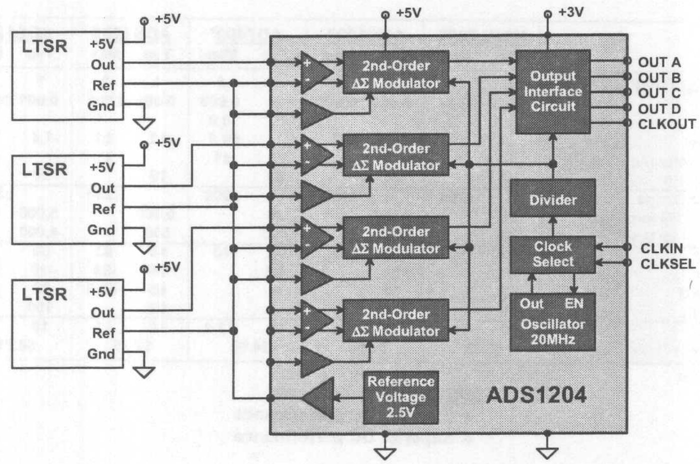
Application Diagram for the ADS1204



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ADS1204: Quad Delta-Sigma Modulator for Industrial Motor Control

		HCPL7860		ADS1202		AD7400*		ADS1203		ADS1204	
		Typ	Max	Typ	Max	Typ	Max	Typ	Max	Typ	Max
INL (@16bit)	LSB	6	60	3	12		4	1	3	1	3
INL	%	0.01	0.14	0.005	0.018		0.006	0.001	0.005	0.001	0.005
DNL	LSB		2		1		0.9		1		1
Offset	mV		±3	±0.3	±1		±0.5	-0.2	±1	-1.4	±1
Vref tolerance	%		±4		±2		±1		±1		±2
Vref drift	ppm/°K	60		20		60		20		20	
Input Range	mV		±200		±250		±200		±250		±2,000
@ fsig	Hz	35		5,000		35		5,000		5,000	
@ Vpp	mV	400		500		400		500		4,000	
SNR	dB	73	62	70.5	67	76	70	85	83	89	86
THD	dB	-67		-84		-80		-95	-88	-96	-88
SINAD	dB	66		70		-		85	82.5	89	85
CMRR	dB	60		90		-		92		100	
Fclk	MHz	10	13.2	10	12	10	13.2	10	11	10	12
Price	1k	$5.50		$2.50		$4.00		$2.75		$6.75	

* Target

ADS120x products have:

- Superior AC performance
- Superior DC performance

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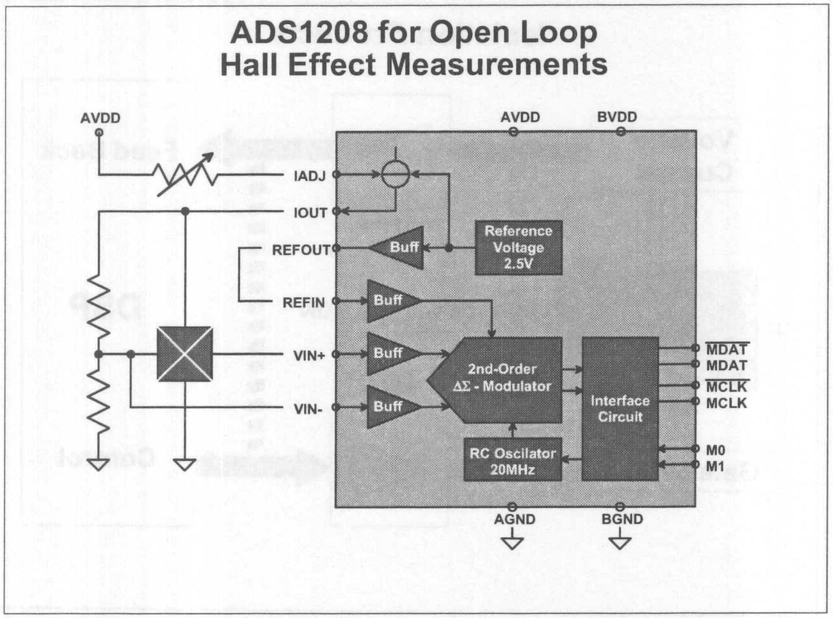

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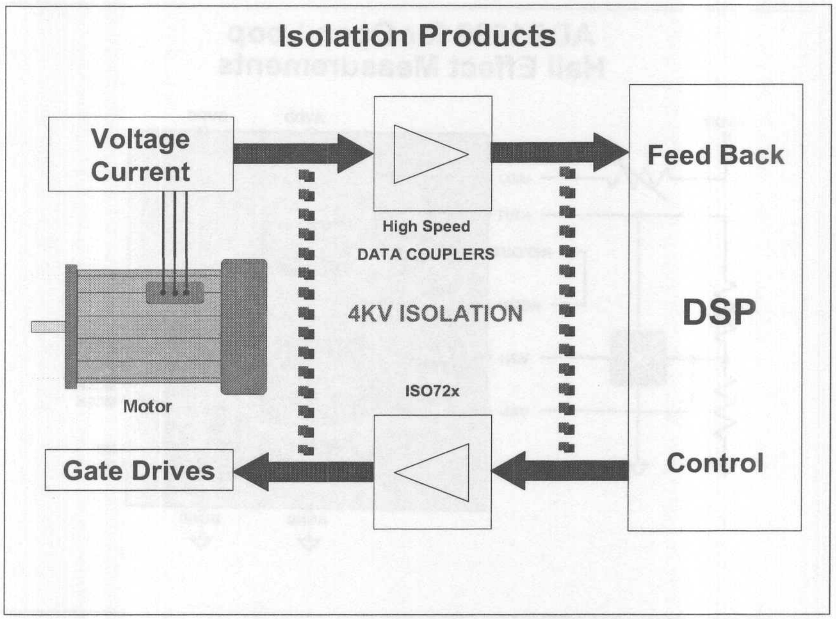
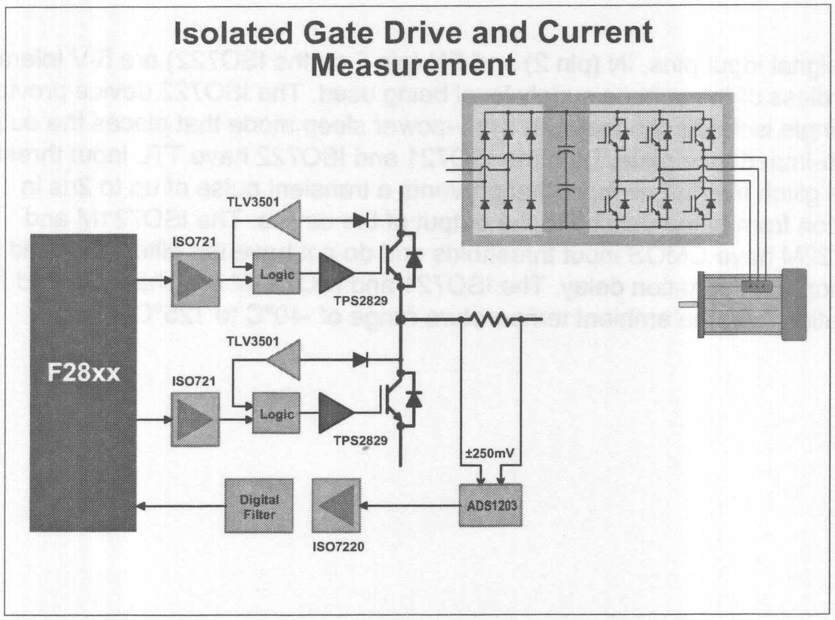


ISO721 and ISO722

These devices are digital isolators with a logic input and output buffer separated by a silicon oxide (SiO2) insulation barrier. This barrier provides galvanic isolation of up to 4000 V. A binary input signal is conditioned, translated to a balanced signal, then differentiated by the capacitive isolation barrier. Across the isolation barrier, a differential comparator receives the logic transition information, then sets or resets a flip-flop and the output circuit accordingly. A periodic update pulse is sent across the barrier to ensure the proper dc level of the output. If this dc-refresh pulse is not received for more than 4 µs, the input is assumed to be unpowered or not functional, and the failsafe circuit drives the output to a logic high state.

The symmetry of the dielectric and capacitor within the integrated circuitry provides for close capacitive matching and allows fast transient voltage changes between the input and output grounds without corrupting the output. The small capacitance and resulting time constant provide for very fast operation with signaling rates up to 100 Mbps. These devices may be powered from either 3.3-V or 5-V supplies on either side in any 3.3-V / 3.3-V, 5-V / 5-V, 5-V / 3.3-V, or 3.3-V / 5-V combination.

The signal input pins, IN (pin 2) and EN (pin 7 on the ISO722) are 5-V tolerant regardless of the voltage supply level being used. The ISO722 device provides the single isolated channel with a low-power sleep mode that places the output in a high-impedance state. Both the ISO721 and ISO722 have TTL input thresholds and a glitch filter at the input that prevents a transient pulse of up to 2ns in duration from being passed to the output of the device. The ISO721M and ISO722M have CMOS input thresholds and do not have the glitch-filter and the additional propagation delay. The ISO721 and ISO721M are characterized for operation over the ambient temperature range of -40ºC to 125ºC.



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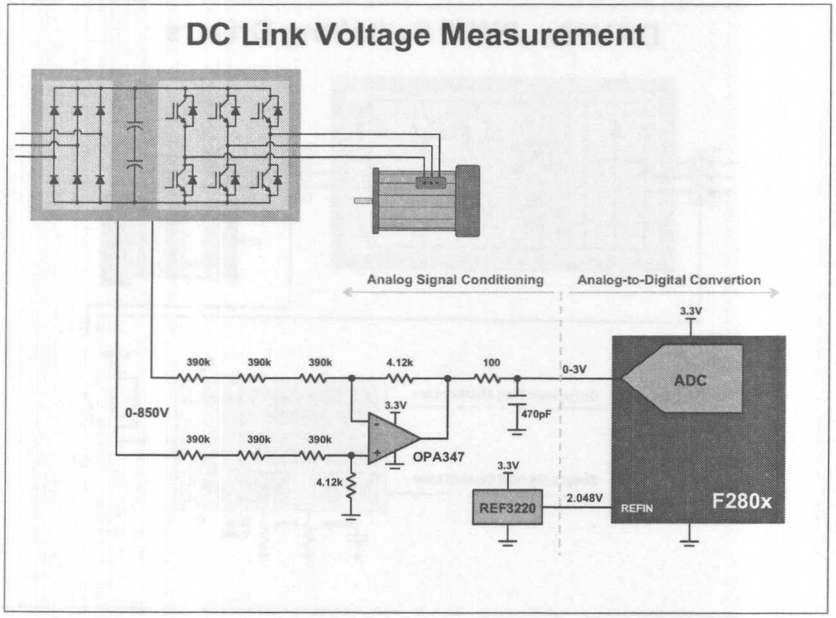
Digital Motor Control



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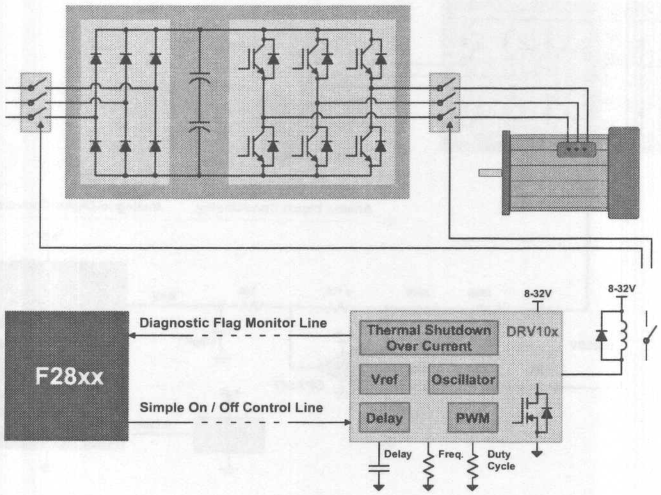
DRV10x: PWM Switching Drivers



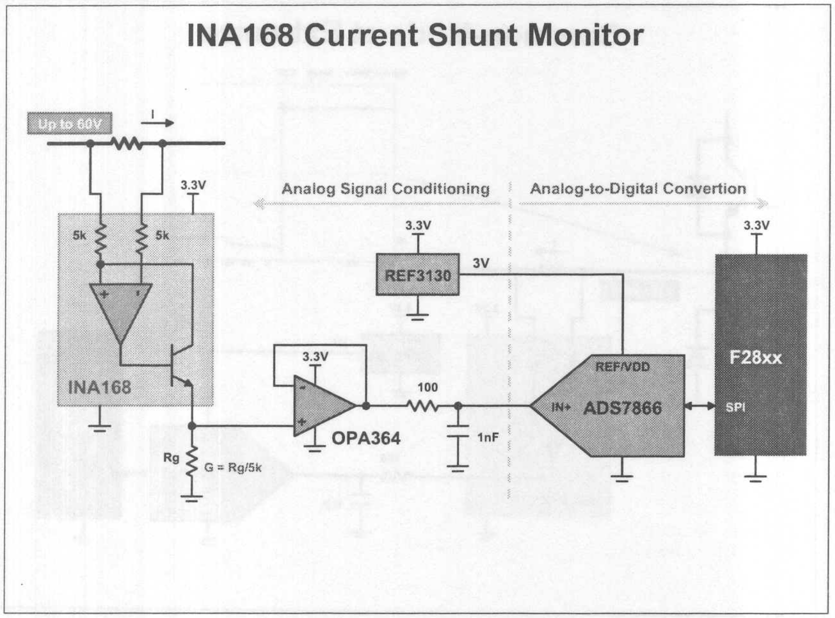
The DRV103 and DRV104 are high efficiency switches with internal oscillator and PWM circuitry. Utilizing high voltage process, they drive 1A up to 3A and operate up to 60V supplies. They are turned on and off by a single digital line, are thermally and over-current protected, and have a digital diagnostic output flag.

Power Switch PWM DRV Applications

- ELECTROMECHANICAL DRIVER:

  Solenoids, Valves, Positioners, Actuators,

  Relays, Power Contactor Coils, Heaters, Lamps
- HYDRAULIC AND PNEUMATICS SYSTEMS
- PART HANDLERS AND SORTERS
- CHEMICAL PROCESSING
- ENVIRONMENTAL MONITORING AND HVAC
- THERMOELECTRIC COOLERS
- DC MOTOR SPEED CONTROLS
- MEDICAL AND SCIENTIFIC ANALYZERS
- FUEL INJECTOR DRIVERS



A shunt at a high voltage.

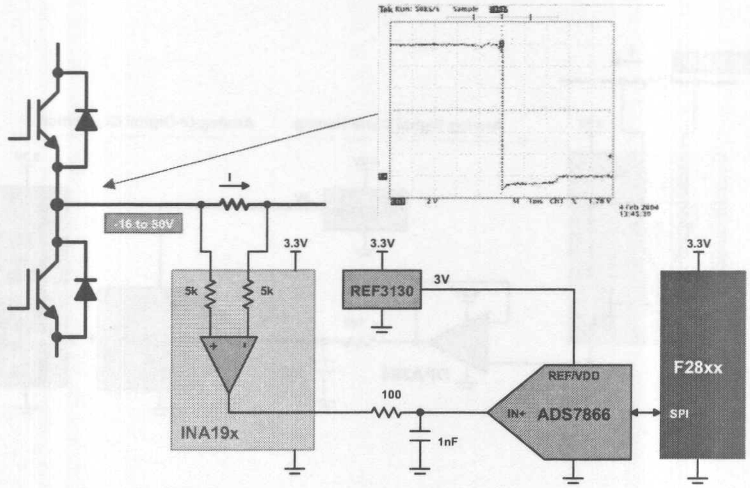
An ADC or processor at low voltage

How do we connect them?

A unique class of amplifier: The Current Shunt Monitor.

Inputs can be connected to voltages well in excess of the amplifier supply voltage.

Common-Mode at Extremes



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High Performance Analog Outline

- **Part I: Signal Chain Overview**
  - Accuracy vs. Resolution
  - Datasheet and Reference Voltage Concerns
- **Part II: Data Converter Drive Concerns**
  - Low Voltage Drive to Embedded ADC
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  - Current Shunt Monitors
  - Isolation Solutions
- **Part V: Tools for High Performance Analog**

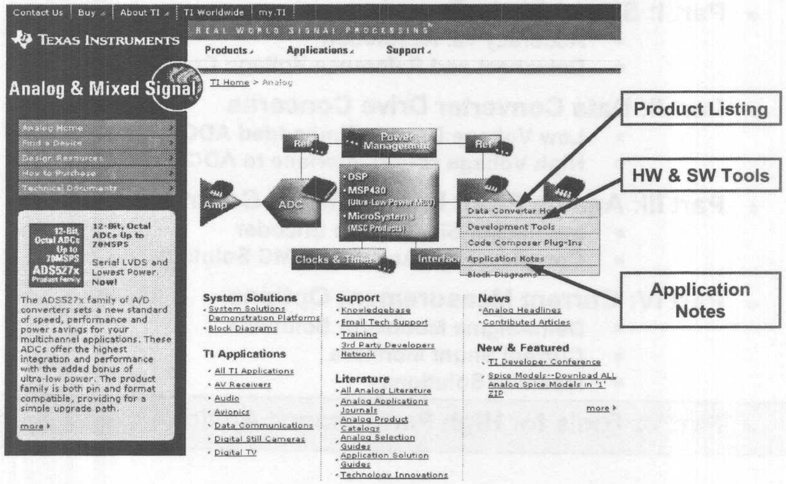
Part V: Tools for High Performance Analog

Several software tools currently exist to help streamline the design of High Performance Analog offerings from Texas Instruments. For operation amplifiers, we have the Totally Interactive Network Analysis (TINA-TI) tool from Design Soft. This is a specially designed version of TINA Pro, customized for Texas Instruments, Inc. Tina-TI is a free download from www.ti.com/tina-ti.

For Data Converters, we have a plug-in module to Code Composer Studio which helps both analog and digital engineers simply the task of writing drivers to communicate with external ADC's and DAC's. The Data Converter Support Tool can be downloaded as part of the Update Advisor from within Code Composer Studio. The support tool can also be downloaded from the following URL: http://focus.ti.com/docs/toolsw/folders/print/dcpfreetool.html

For Power Management Products, we have three software tools to simplify DC/DC converter designs. SWIFT Designer is for use with the TPS54000 DC/DC converters. For TPS40000 and TPS60000 series controllers, we have TPS40K and TPS62K Controller Products Design Software. All three tools and a variety of other power related design tools are available from Power.TI.COM.

Where to Start: Analog.TI.Com



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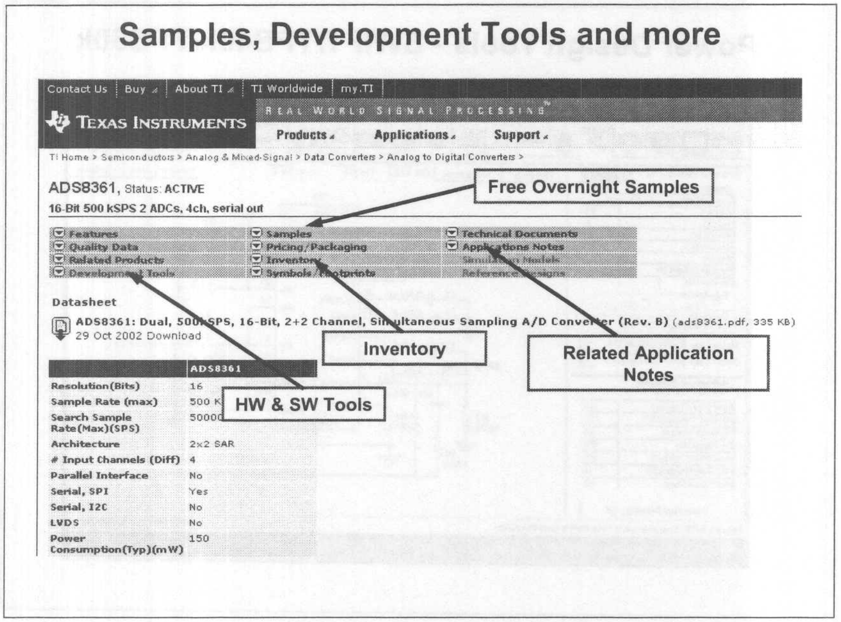


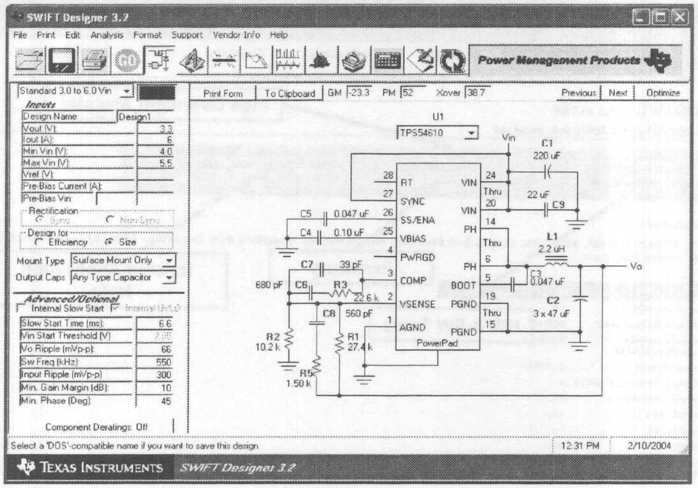
How do I get more information about a specific product?

The slide above represents a product folder for a specific device – in this case it is the ADS8361, a device mentioned previously or use with resolver or encoder feedback in DMC systems. If you know what device you'd like additional information on, simply enter the part number in the Part Number Search window from www.ti.com.

The search will return a product folder like the one shown above. From a device product folder, you can access device specific applications notes, information regarding the available packaging, information of Lead Free status – even Distributor and Factory stock information. Tools associated with the device – such as EVM's and Data Converter Plugins in this case – can also be found here.

Need Samples? The product page allows you to order Free Samples on nearly every device Texas Instruments make, delivered overnigh in most cases.

Power Design Tools - SWIFT/TPS40k/TPS60k



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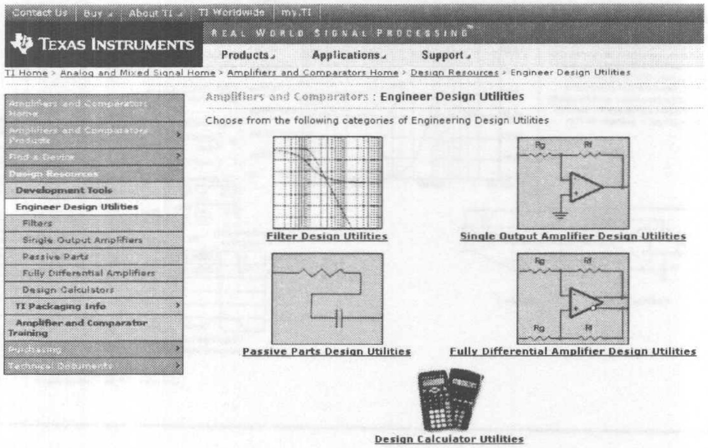
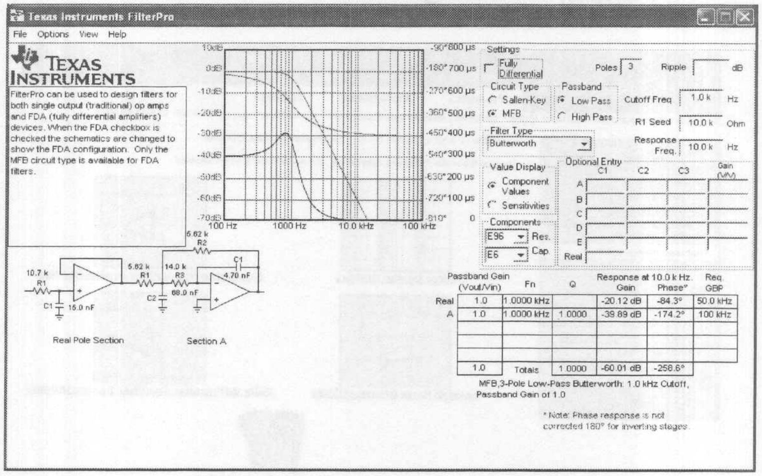
Amplifier Design Tools - Calculators



Calculators for a variety of Op Amp Calculations:

Analog Design Tools - FilterPro



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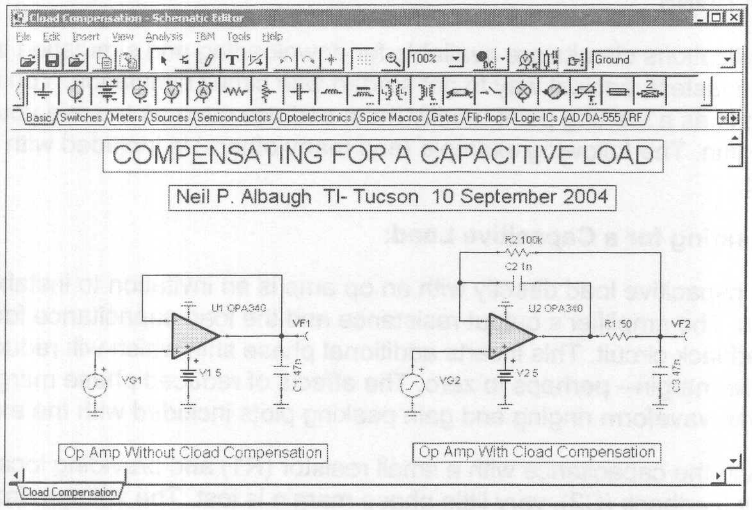
Analog Design Tools – TINA-TI



Totally Interactive Network Analysis for Texas Instruments -

TINA stands for Totally Interactive Network Analysis. Based on a SPICE engine, TINA-TI provides all the conventional DC, transient and frequency domain analysis of SPICE and much more. TINA has extensive post processing capability that allows you to format results the way you want them. Virtual instruments allow you to select input waveforms and probe circuit nodes voltages and waveforms. TINA's schematic drawing and capture is truly intuitive-a real "quickstart." This complimentary version, TINA-TI, is fully functional but limited to simulating two ICs+ 20 nodes. Texas Instruments' macromodels are preloaded. TINA-TI download is a 19MB Zip file and installation requires approximately 30MB. Installation is straight-forward and it can be uninstalled easily, if you wish. We bet that you won't. TINA is a product of DesignSoft and this special complimentary version, TINA-TI is prepared by DesignSoft exclusively for Texas Instruments.

Links:

For more about SPICE models, including for other simulators – please visit the Analog home page by entering

ANALOG.TI.COM

in your browser address window. You can also download the free ***TINA-TI tool*** here:

http://focus.ti.com/docs/toolsw/folders/print/tina-ti.html

APPLICATIONS

Many applications circuits are available for downloading and simulation in TINA. This is the fastest, easiest way to get started with circuit simulation. You use these applications as a starting point-modify them and use save-as to save your own circuit design. The following example (and many others) is included with the free download.

Compensating for a Capacitive Load:

Driving a capacitive load directly with an op amp is an invitation to instability or oscillation. The amplifier's output resistance and the load capacitance form a pole in the feedback circuit. This inserts additional phase shift which will reduce the loop phase margin-- perhaps to zero. The effects of reduced phase margin can be seen in the waveform ringing and gain peaking plots included with the example.

By isolating the capacitance with a small resistor (R1) and providing local high-frequency feedback (C2), very little phase margin is lost. The voltage drop across R1 is sensed by a DC feedback connection (R2) to the circuit output and thereby reduced to virtually zero. Note the improvement gained by compensating for a Capacitive load!

DesignSoft, Inc. Links:

For a comparison of full featured versions of TINA visit the TINA website at www.tina.com

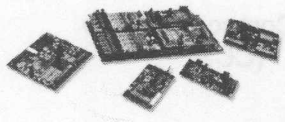
TI recommends Tina Pro Classic, or for even more capability including optimization and nested parameter stepping, TINA Pro Industrial. Discount pricing is available from DesignSoft at the following URL:
http://www.tina.com/ti-upgrade.htm

High Performance Data Converters for Motor Control

- **New – HPA-MCU Interface Board**
  - **Designed for compatibility with C2000 eZdsp™ Boards**
- **DMC Related Application Notes**
  - **Using a SAR A/D Converter for Current Measurement in Motor Control Applications (sbaa081.htm)**
  - **Understanding the CAN Controller on the TMS320C24x DSP Controller (spra500.htm)**
  - **RS-485 for Digital Motor Control Applications (slla143.htm)**
  - **Interfacing the ADS8361 to the TMS320F2812 DSP (slaa167.htm)**
  - **Interfacing the ADS8364 to the TMS320F2812 DSP (slaa163.htm)**

Signal Chain
Prototyping System

Use mini-EVM boards to prototype a complete data acquisition system in 10 minutes!



Application Collateral

Evaluation Boards complete with User's Guide, Schematic, & BOM on web

Device specific application notes – linked directly from product folder!

Code Composer Studio Example Projects for C2000, C5000, C6000 DSP's

Complete "Signal Chain" prototyping system for C2x processors using the HPA-MCU Interface Board! Supports eZdsp™ development systems.

EVM's available for purchase at www.ti-estore.com

Related Application Notes

Using a SAR A/D Converter for Current Measurement in Motor Control Applications (sbaa081.htm)

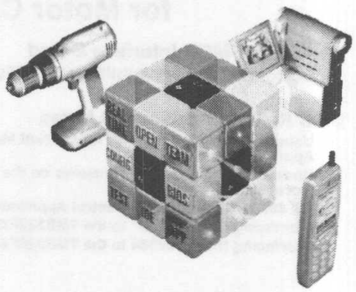
Understanding the CAN Controller on the TMS320C24x DSP Controller (spra500.htm)

RS-485 for Digital Motor Control Applications (slla143.htm)

Interfacing the ADS8361 to the TMS320F2812 DSP (slaa167.htm)

Interfacing the ADS8364 to the TMS320F2812 DSP (slaa163.htm)

Data Converter Software Plug-In



Data Converter Software support

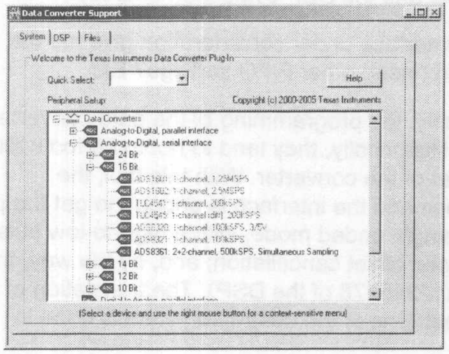
embedded into

Code Composer Studio (CCS)

Data Converter Foundation Software:

The Data Converter Support tool is based on the open plug-in architecture of Texas Instruments Code Composer Studio and facilitates the work with TI's data converters.

Software Support: The Converters



- **Select:**
  - Virtually any number of data converters
  - Nearly every combination (limitation is the DSP)
- **Supports:**
  - Analog to Digital converters
  - Digital to Analog converters
  - Codecs
  - For a complete list of supported devices, visit http://www.ti.com/sc/dcplug-in
- **Not hardware specific:**
  - Can be used on the analog EVMs or with the customer's own hardware, as long as there is no special hardware setup necessary (e.g. controlling a multiplexer)

- Supports TMS320F280x and TMS320F281x Processors
- Provides complete drivers for 19 DAP devices

Software Drivers for Data Converters?

Many modern data converters need software support due to on chip features such as input channel selection, filters (i.e. decimation ration in Sigma Delta Modulators), built in FIFO support and gain (PGA settings). Some data converters also have as more than 40 registers and 640 control-bits. Coding the software in these cases can be tedious and requires a "more than basic" understanding of how the parts work.

Cool! – I'm a DSP guy, and I don't want to learn how the analog portion of the converter works…

The data converter software support tool (aka Data Converter Plug-In DCP) was created to support customers with the complex task of programming state of the art data converters. It can be used in the following development stages:

- Evaluation of the analog part: Reprogramming is done very easily, thus making it possible to evaluate the features of the data converter in a very short time (especially, if used together with the analog EVMs and the DSP evaluation boards)

- Evaluation of the interface: Does the interface under consideration give me the bandwidth needed for the system? Do I need other FIFO settings? Etc

- Creating the production software: Mostly, the programming of the data converter is done by the DSP software designer. Historically, they tend to not to be too willing to dig deeply into the "analog" data sheet of the converter. With this tool, the specification of the analog performance and the interface is enough to get the part working (we need three channels in single ended mode, with a high-to-low pulse on the end of conversion pin and automatic offset cancellation; and, by the way, the converter is connected to address 0x12345678 of the DSP). The translation of this requirements into the necessary bit patterns of the control registers is done in seconds.

But I'm an Analog guy…I don't know even know how to spell "DSP"…

The Data Converter Support Tool was developed with the Analog Designer in mind. An analog designer, with basic knowledge of how to start Code Composer Studio, would not have to ask the DSP programmer for help if they need some parameters changed for testing purposes. They can do that on their own.

- Each added converter in the system screen adds it's own tab, where the settings can be configured as described independently through a GUI.

- The limiting factor for adding converters to the system is the DSP: You can only add as many converters, as resources are available; e.g. it is not possible to add four serial converters, if the DSP has only three serial ports. The same is applicable to parallel converters.

- The created software is not directly related to any specific hardware: It can be used together with the EVM's we have available for most data converters and the DSP DSK's for TMS320C2000, TMS320C5000 and TMS320C6000, but it is not limited to these platforms. The software will run on any customer created hardware using a TI DSP family that has the converter directly connected to the host. We do not support special setups like multiplexing converters or complex address decoding, however all the files generated are in C, the end user can take our generated software files as a starting point and can modify the sources to accommodate his hardware setup.

How would I get started using the tool?

The Data Converter Support Tool is an integral part of the Code Composer Installation (full or DSK version). Updates to the tool can be downloaded through the Update Advisor found in the full version of Code Composer Studio or downloaded through the web. If you have trouble finding updates, feel free to contact your local Field Sales office or send e-mail to the Data Converter Applications group at dataconvapps@list.ti.com.

Texas Instruments

Thanks for your Time!

Texas Instruments

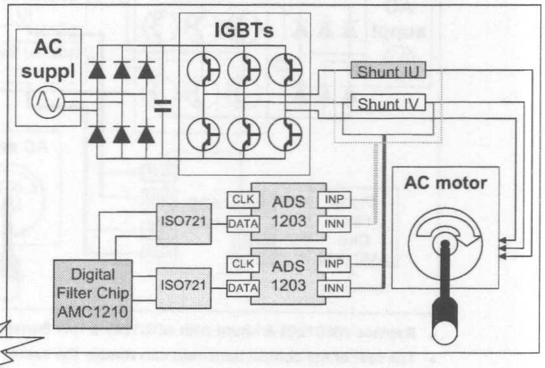
Delta-Sigma Product Appendix

Current Measurement using shunt resistor

ADS1203:
- best in Noise
- lowest Power
- highest Speed

ISO721:
- highest Speed
- Capacitive Isolation

AMC1210:
- only quad digital filter on the market

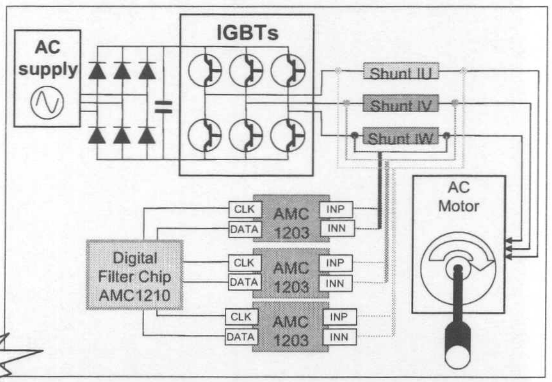


AMC1210
in development

Current Measurement using shunt resistor

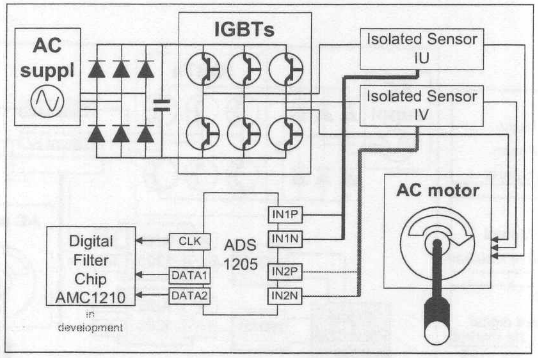
AMC1203:
- Capacitive Isolation
- best in Noise
- lowest Power

Best product variation:
- 10MHz (Power opt.)
- 20MHz (Speed opt.)
- Internal Clock (2006)
- External Clock (2007)



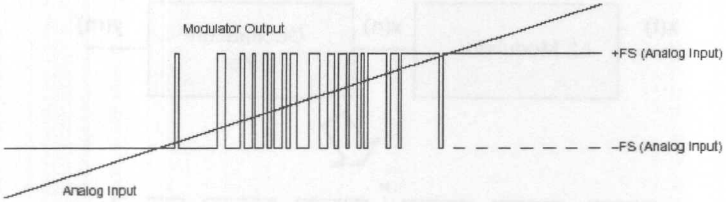
AMC1203/AMC1210
in development

Use Modulators to stay consistent with shunt modules



- **Replace AMC1203 & shunt with ADS1205 & Hall Sensor**
- **The rest of the control hardware can remain the same**

Delta-Sigma Modulator Output



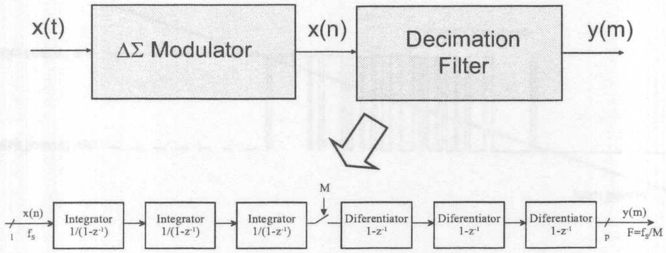
Simplified digital output data stream of the modulator

- The pulse width is proportional to the input voltage

Simplified output of a Delta-Sigma Modulator:

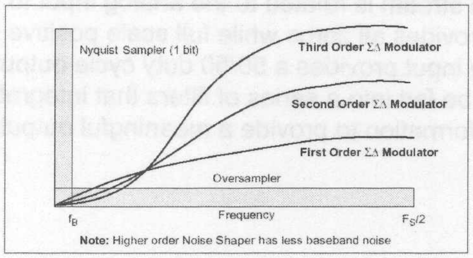
The digital output of a Delta-Sigma Modulator is essentially a PWM data stream. The data stream is related to the analog input to the device – full scale negative provides all zeros while full scale positive input provides all ones. Mid Range input provides a 50/50 duty cycle output. This data stream needs to be fed into a series of filters that integrates and then decimates the information to provide a meaningful output to the control system.

Decimation Filter



The modulator output data stream x(n) must be processed by an decimation filter

Quantization Noise



$$Q(f) = \frac{V_{LSB}}{\sqrt{12 \cdot f_S}} \cdot \left(2 \cdot \sin \pi \frac{f}{f_S} \right)^K$$

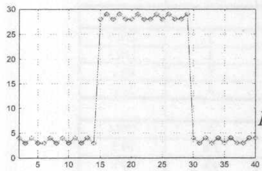
Q(f) The quantization noise as function of frequency
K Implemented order of the ΔΣ modulator,
f_S Sampling frequency
V_{LSB} Value of the last significant bit

Filter Order and its effects on Noise:

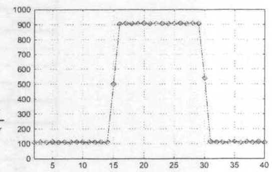
Decimation Filter

Pulse Response of Sinc^K Filters

Sinc^1
K=1
M=32

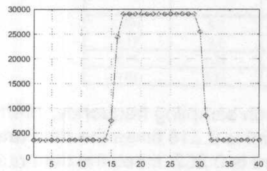


Sinc^2
K=2
M=32



$DataRate = \frac{f_S}{M}$ Output data rate, or first notch frequency

Sinc^3
K=3
M=32



$K \geq 1 + (order\_\Delta\Sigma)$ The order of the filter

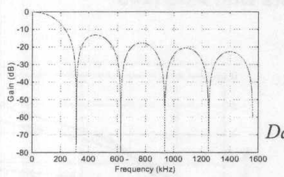
$p = K \cdot \log_2 M$ Output word size

Over Sampling Ratio versus Pulse Response:

Decimation Filter

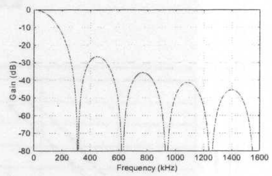
Frequency Response of Sinc^K Filters

Sinc^1
K=1
M=32



f_{-3dB}=138kHz

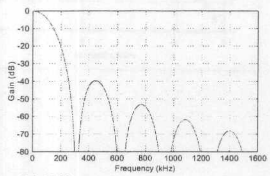
Sinc^2
K=2
M=32



f_{-3dB}=99.5kHz

$DataRate = \frac{f_S}{M}$ Output data rate, or first notch frequency

Sinc^3
K=3
M=32



f_{-3dB}=81.8kHz

$K \geq 1 + (order\_\Delta\Sigma)$ The order of the filter

$p = K \cdot \log_2 M$ Output word size

Over Sampling Ratio versus Frequency Response:

Decimation Filter

Example results with ADS1203

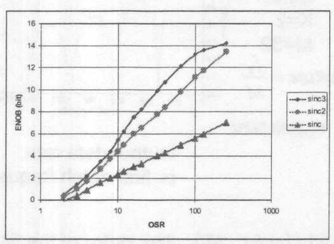
Decimation	Data rate [kHz]	ENOB [Bit]	f-3dB [kHz]
$Sinc^1$			
16	625	3	276.9
32	312.5	4	138.3
64	156.2	5	69.1
128	78.1	6	34.6
$Sinc^2$			
16	625	6	199.4
32	312.5	7.8	99.5
64	156.2	9.8	49.8
128	78.1	11.7	12.9
$Sinc^3$			
16	625	7.5	163.7
32	312.5	9.9	81.8
64	156.2	12.1	40.9
128	78.1	13.6	20.4

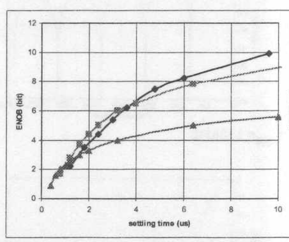
Data rate is M times smaller than sampling frequency, 10MHz.
$Sinc^2$ filter –3dB response point is 0.318 times the data rate.
$Sinc^3$ filter –3dB response point is 0.262 times the data rate.
This point is very dependant of the filter order and less of the decimation ratio.

Over Sampling Ration versus Resolution:

Decimation Filter

Example results with ADS1203





Over Sampling Ratio versus Settling Time:

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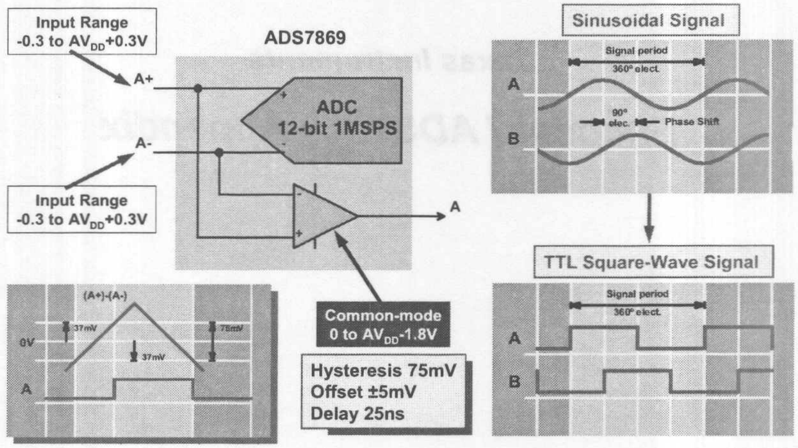
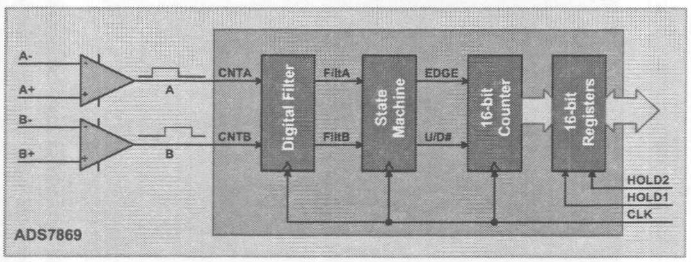
Encoder / ADS7869 Appendix

Sign Comparators for Encoder Sinusoidal Signal

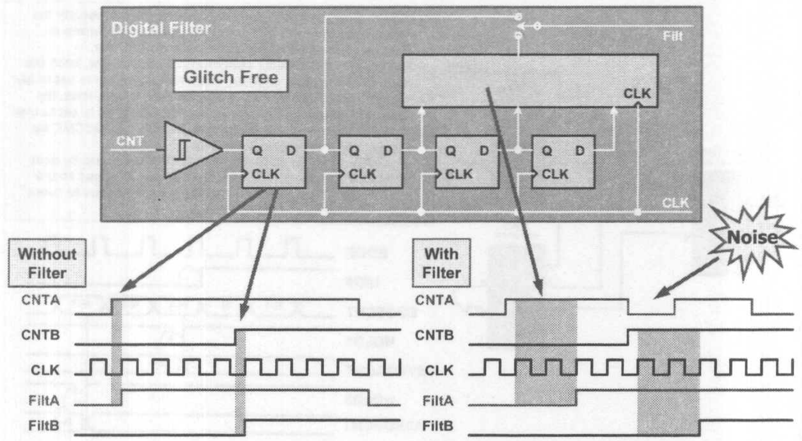


16-bit Up/Down Counter from ADS7869 Structure

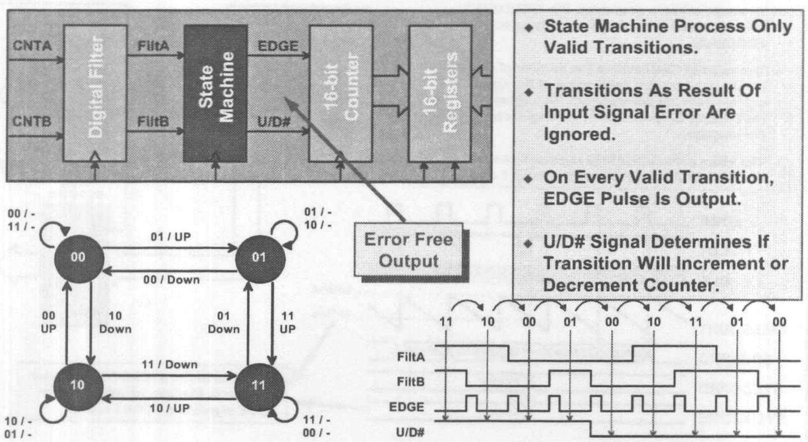


- Clock frequency up to 16MHz, input data rate up to 2MHz
- Synchronous operation to the system clock
- Digital Noise Filter
- Error-safe state machine for fully four quadrant decoding
- 16-bit binary Up/Down counters with over- and under-flow detection
- Asynchronous and synchronous latching of the counter values at the same time as the ADC values are sampled and held
- Five shadow registers

Digital Filter from ADS7869 Counter

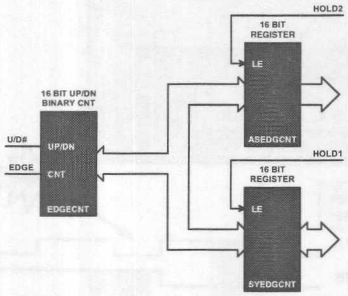


State Machine from ADS7869 Counter

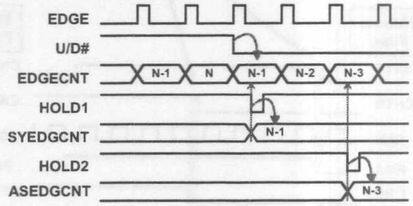


- State Machine Process Only Valid Transitions.
- Transitions As Result Of Input Signal Error Are Ignored.
- On Every Valid Transition, EDGE Pulse Is Output.
- U/D# Signal Determines If Transition Will Increment or Decrement Counter.

Edge Counter from ADS7869 Counter

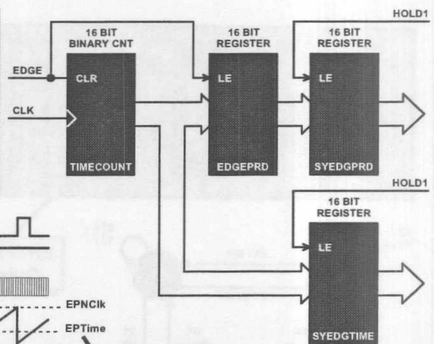


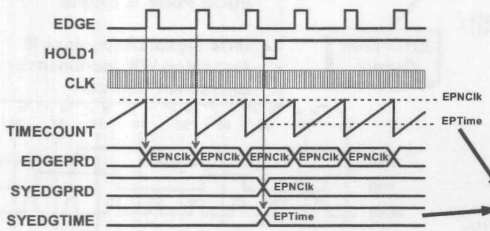
- HOLD1 signal is synchronous sampling signal, usually the PWM or control loop timer, and HOLD2 is asynchronous.
- There are two shadow registers per edge counter.
- The register SYEDGCNT synchronous edge count, latch the value from the edge counter, when HOLD1 signal is set to low.
- Register ASEDGCNT, asynchronous edge count, latch the value from the edge counter when HOLD2 signal is set to low.
- An initial value is given to the edge counter, EDGECNT, by writing into the register SYEDGCNT.
  - The 14 MSBs (D15−2) of EDGECNT are setup by user
  - The 2 LSBs (D1−0) of EDGECNT are adjusted to the value of the FiltA and FiltB by a write access to these register or a reset condition.



Registers from ADS7869 Counter

- When the EDGE signal rises, the TIMECOUNT value is latched into the shadow register EDGEPRD.
- The value of EDGEPRD is the number of system clocks between two valid edges of the input signals from the comparators. This value is reciprocally proportional to the angular speed of the encoder.
- The value in the EDGEPRD register is latched in the SYEDGPRD Register on the HOLD1 signal.





The value of the SYEDGTIME register represents the time between the last EDGE signal and HOLD1 signal.

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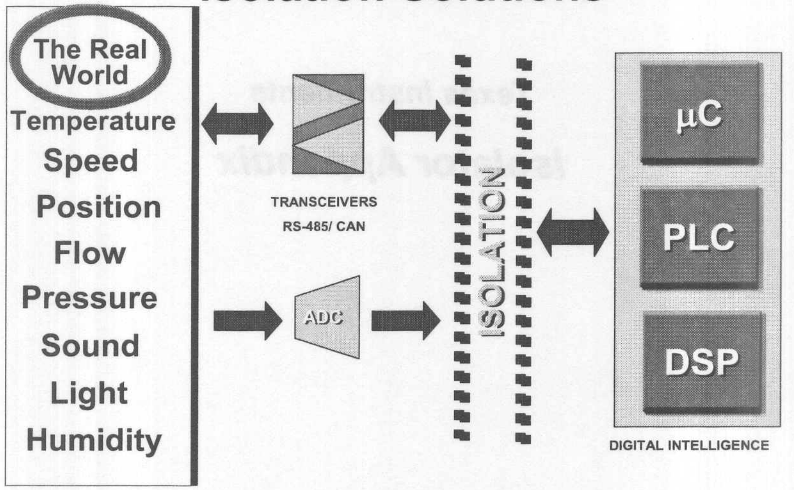
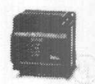
Isolator Appendix

Isolation Solutions



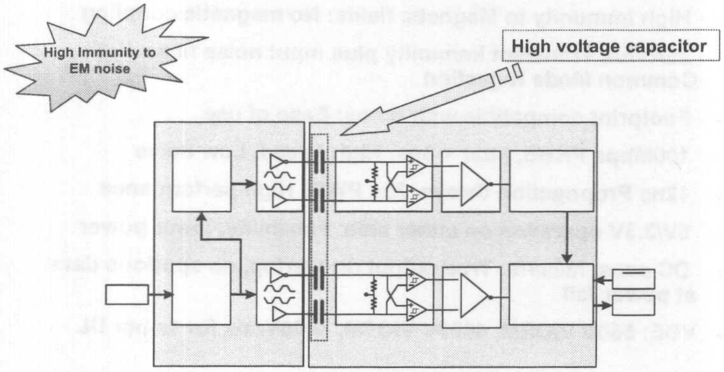
Target Applications



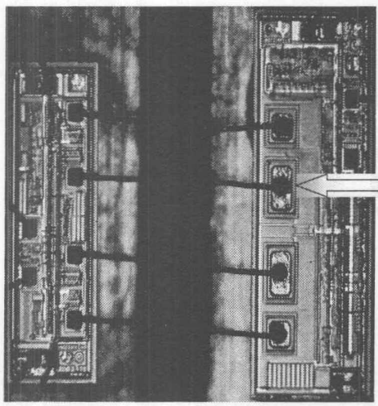
High Performance Industrial Automation

- Motor control: Need higher speeds for over-current protection
  - Shunt method: 10 to 20 MHz
- FieldBus (Sensor & actuators): Loop delays (propagation delay) and PWD (skew) is critical
  - General RS-485 based phy: 25Mbps and higher
  - ProfiBus, InterBus: 10Mbps to 25Mbps
  - MODBus, DeviceNet, SDS: ~ 1Mbps
- PLC input/output isolation
  - Lower speeds but need fast prop delays, low PWD
- Data acquisition modules
  - 1Mbps or lower.

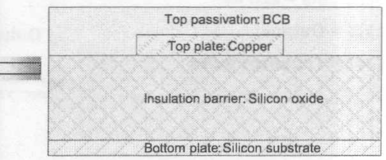
Capacitive Technology



Capacitive Technology



ISO721 IN 8SOIC



High Voltage Capacitor design

Product Highlights

- High immunity to Magnetic fields: **No magnetic coupling**
- 25KV/us Transient Immunity **plus** input noise filter: **High Common Mode Rejection**
- Footprint compatible with optos: **Ease of use**
- 100Mbps PRBS, jitter < 3ns: **High speed, Low noise**
- 12ns **Propogation delays,** 2ns **PWD: High performance**
- 5V/3.3V **operation on either side: Flexibility, lower power**
- DC pass, failsafe: **True output on startup, no spurious data at power fail**
- VDE: 560V **VIORM,** 4000V **VIOTM,** 3000Vrms **for 1s per UL**

Transient Immunity, 1KV

Transient Immunity = 44 KV/us

Vcc=3.0V

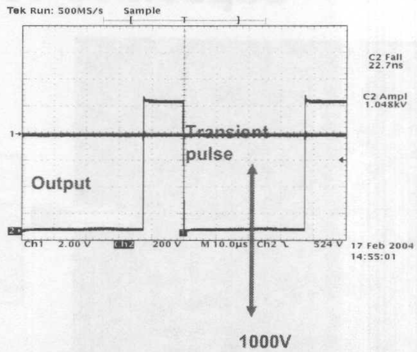
Input Low

CM = 1KV

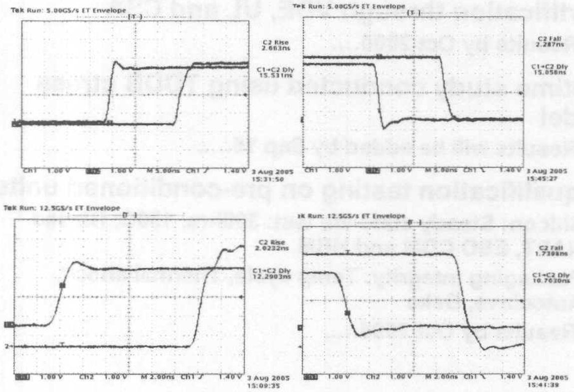
Rise time = 22.7ns

CH1 = Output

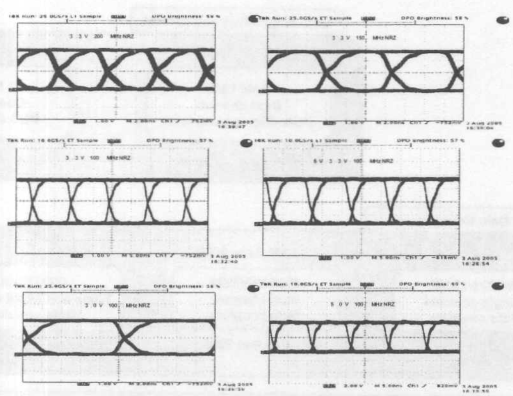
CH2 = Transient pulse



Transition times, Prop delays



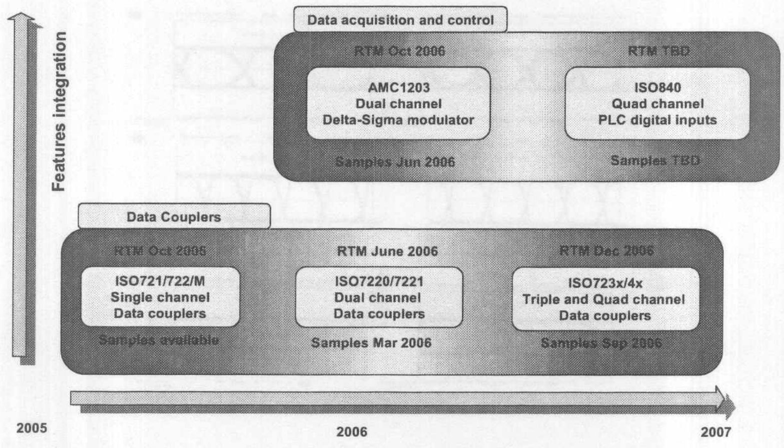
Eye patterns



Lifetime & Reliability

- Certification through VDE, UL and CSA
  - Results by Oct 2005....
- Lifetime study conducted using TDDB stress model
  - Results will be added by Sep 15.....
- TI qualification testing on pre-conditioned units
  - Silicon: Steady state life test: 300hrs, 150C; Biased HAST, ESD CDM and HBM
  - Packaging integrity: Temp cycle, Thermal shock, Autoclave, Bake
  - Results by Oct 2005.....

Isolation Roadmap



Comparing solutions

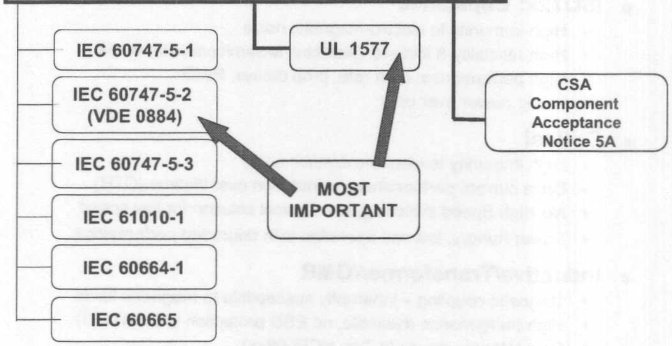
- **ISO72x: Capacitive**
  - High immunity to electro-magnetic noise
  - High reliability & lifetime: Dielectric is semiconductor oxide
  - High performance: data rate, prop delays, PWD
  - Lower power over opto
- **Optical**
  - High immunity to electro-magnetic noise
  - Drive current performance degradation over lifetime (CTR)
  - No High Speed switching, economical solution for low speed
  - Power hungry, low volt operation with degraded performance
- **Inductive/Transformer/GMR**
  - Magnetic coupling – inherently susceptible to magnetic fields
  - High performance available, no ESD protection (ADuM1100)
  - Data integrity issues (IL7xx; HCPL09xx)
  - Low power over opto

High Speed Isolators

	ISO721	ISO721L	AduM1100 (Magnetic)	HCPL-0721 (Opto)	ISO150	IL71x (GMR)
Data rate, Mbps	100	100	100	25	80	100
Magnetic coupling	No	No	Yes	No	No	Yes
KV/us, 5V	25	25	25	10	1.6	20
Prop delay, 5V	20	15	18	40	40	15
PWD, ns	3	2	2	8	6	3
Icc (mA), Q (per channel)	10	2	1	19		
Icc (mA), 25Mbps	16.2	4.8	4.5	23	21	12.5
Icc (mA), 100Mbps	29.8	12.8	16.8	-	-	
Temp (deg C)	-40 to 125	-40 to 125	-40 to 125	-40 to 85	-40 to 85	-40 to 100
Vcc, V	5, 3.3	5, 3.3	5, 3.3	5	5	5, 3.3
Isolation, V	4000	4000	4000	4000	2400	3500
DC pass	yes	yes	yes	yes	no	no
Failsafe o/p	yes	yes	yes	yes	no	no
Input noise filter	yes	yes	yes	NA	no	no

Note: Values for ISO72xx products are not final

Isolation Standards



Isolation Standards Terminology

Insulation Classification:

Basic insulation – Insulation to provide basic protection against electric shock.

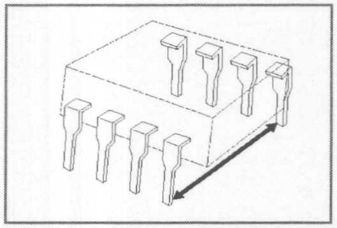
Supplementary insulation – Independent insulation applied in addition to Basic insulation in order to ensure protection against electric shock in the event of a failure of the Basic insulation.

Double insulation – Insulation comprising both Basic and Supplementary insulation.

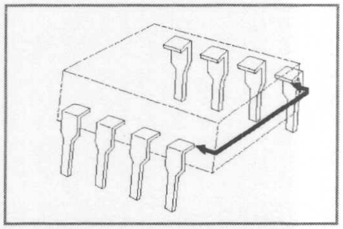
Reinforced insulation – A single insulation system which provides a degree of protection against electric shock equivalent to Double insulation under the conditions specified in this standard.

TI's isolation products provide *BASIC INSULATION*

Isolation Standards Terminology



Clearance – The shortest distance between two conductive input to output leads measured through air (line of sight).



Creepage Distance – The shortest path between two conductive parts measured along the surface of the insulation. The shortest distance path is usually found around the end of the package body

Isolation Testing

Isolation test voltages are applied between the input and output with the input-side pins tied together and the output-side pins tied together, making it a two-terminal device.

Yearly testing and certification is required, as well as final production testing.

UL1577 and CSA rate isolation devices on the basis of their dielectric withstand voltage capability, regardless of creepage and clearance dimensions.

UL1577 mandates a production test of 120% of the rated withstand voltage for a period of 1s. For a TI device, this is a 3000 VRMS or 4242 Vpeak test, performed for 1s.

The IEC 60747-5-2 (VDE 0884 REV 2) ratings are based upon the dielectric strength of the insulation material in addition to creepage and clearance.

IEC 60747-5-2 defines a production test of 1.875 times the working voltage rating for 1s. For a TI device, this is a 1050 Vpeak test, performed for 1s.

Section 14

Additional Information on Products, Tools and Support From Texas Instruments

Motor Types : Overview

http://www.ti.com/motorcontrol

In today's competitive market, motor control systems are becoming increasingly complex, placing more demands on the entire control signal chain. DSP-based controllers have emerged as the processing muscle that is best suited for improving calculating power of the overall system. Analog front-end devices, including analog-to-digital / digital-to-analog converters and operational amplifiers, are playing the central role of providing the DSP with accurate data and moving overall system performance one step forward.

As motor systems continue to evolve with advanced features such as sensorless vector control, current-shaped control, and field-oriented control, system designers will benefit from the use of application-specific DSPs , high-performance converters and analog interface circuits specifically designed and matched to reduce system costs while increasing overall performance. In addition, hardware development tools will dramatically reduce development time; mini-EVMs, for example, permit many combinations of converters and operational amplifiers to match specific DSP application requirements. Simultaneously, these development platforms are supported with Code Composer Studio, permitting easy code development for a wide range of possible combinations. On the other hand, free analog simulation software, TINA, together with other designer utilities and the TI KnowledgeBase, offer designers the capability of easy development and verification of more demanding analog signal processing circuits before passing data to the DSP.

Digital Motor Control

For more information on TMS320C2000™ Digital Signal Controllers please look at the Texas Instruments C2000 home page: **www.ti.com/c2000**

Getting started http://www.ti.com/C2000getstarted

This page provides access to:

C2000 DIGITAL SIGNAL CONTROLLER PRODUCTS

- Alphabetical Product Listing
- Device Locator
- Parametric Search
- Part Number and Keyword Search

DESIGN RESOURCES

- Application Notes
- Datasheets
- Development Tools
- Free Motor Control Software Library
- Packaging Information

HOW TO PURCHASE

- Distributors
- Pricing and Availability
- Samples

SUPPORT

- Ask an Expert
- KnowledgeBase
- News and Publications
- Roadmaps
- Training

For more information on Data Converters please look at the Texas Instruments data converter home page:

www.dataconverter.com

This page provides access to:

DATA CONVERTER PRODUCTS

- Alphabetical Product Listing
- Device Locator
- New Products
- Parametric Search
- Part Number and Keyword Search

DESIGN RESOURCES

- Application Notes
- Datasheets
- Development Tools (EVMs)
- Packaging Information

HOW TO PURCHASE

- Distributors
- Pricing and Availability
- Samples

SUPPORT

- Ask an Expert
- Industry Forums
- News and Publications
- Standards Bodies
- Training

For more information on Amplifiers please look at the Texas Instruments amplifier home page:

www.amplifier.ti.com

This page provides access to:

AMPLIFIER PRODUCTS

- Alphabetical Product Listing
- Analog Cross Refefence Search
- Device Locator
- Parametric Search
- Part Number and Keyword Search

DESIGN RESOURCES

- Application Notes
- Datasheets
- Development Tools
- Engineering Design Utilities
- Packaging Information
- Macro Models

HOW TO PURCHASE

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- Pricing and Availability
- Samples

SUPPORT

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- News and Publications
- Standards Bodies
- Training

Digital Motor Control

For more information on Power please look at the Texas Instruments power home page:

www.power.ti.com

This page provides access to:

POWER PRODUCTS

- Alphabetical Product Listing
- Analog Cross Refefence Search
- Device Locator
- Parametric Search
- Part Number and Keyword Search

DESIGN RESOURCES

- Application Notes
- Datasheets
- Development Tools
- Engineering Design Utilities
- Packaging Information
- Macro Models

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- News and Publications
- Standards Bodies
- Training

For more information on Interface please look at the Texas Instruments interface home page:

www.ti.com/sc/datatran

This page provides access to:

INTERFACE PRODUCTS

- Alphabetical Product Listing
- Analog Cross Refefence Search
- Device Locator
- Parametric Search
- Part Number and Keyword Search

DESIGN RESOURCES

- Application Notes
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TI Home Page

www.ti.com

DSP Developers' Village

www.ti.com/dsp

Analog Home Page

www.ti.com/analog

Applications Home Page

www.ti.com/applications

For information on training

including: on-line training, webcasts, seminars and workshops.

www.ti.com/training